REVIEW OF THE OCEANOGRAPHIC ENVIRONMENT OF THE TONGUE OF THE OCEAN, BAHAMAS

PART II: SURVEY AND ANALYSIS OF OCEAN CURRENT DATA

U.S. NAVAL
UNDERWATER ORDNANCE STATION
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TECHNICAL MEMORANDUM

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FOREWORD

In the Atlantic Undersea Test and Evaluation Center (AUTEC) development program, the Naval Underwater Ordnance Station (NUOS) is responsible for the design, test, and evaluation of the underwater tracking systems. In order to obtain accurate tracking data on test vehicles, the information obtained by the underwater instrumentation must be correlated with the effects of the oceanographic environment.

NUOS has obtained data on the undersea environment in the Tongue of the Ocean (TOTO) from many sources, and has collated and reprocessed the data on water currents according to the collection method used. In this report, a survey and an analysis of the available data are made, and a general description of the water currents in TOTO is presented.

Additional drogue measurements were made, with a few exceptions, as outlined in the recommendations in this report. NUOS TM No. 306 describes the purpose of the measurements, the drogue system and type of navigation used. Analysis of the data will be the subject of a subsequent report.

This work was accomplished under Weptask Assignment No. RU22-2E-000/219-1/R004-03-01 and RUTO-BF-000/219-8/SF09-90-302.

ABSTRACT

This report presents a survey of all the water current data obtained in the Tongue of the Ocean (TOTO) since August 1958. The methods used to measure the water currents are described and the data are analyzed separately for each method used. The quality of the data is evaluated from the viewpoint of temporal and spatial distribution with depth, the method of measurement, and the navigation system in use. Using the data collectively, the average water currents (surface, subsurface, and bottom), vertical shear, turbulence, and general circulation patterns in TOTO are discussed.

The distribution of the existing data was sporadic in both time and space, indicating that a more systematic and synoptic coverage of the water currents in TOTO is needed before the effects of the ocean medium on tests and evaluations conducted with underwater tracking systems can be determined. An intensive, well-planned program to measure the water currents in TOTO is recommended and the initial phase of such a program is outlined.

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INTRODUCTION

The number of water current measurements (figures 1 and 2) taken in the Tongue of the Ocean (TOTO) since August 1958 has been relatively small compared with the area to be covered. In many cases the observation times were less than one day (two tidal periods); hence these data can hardly indicate the existence of currents of a tidal period or longer. However, it was considered that, in order to learn more about the general circulation in TOTO, all the available data on the water currents should be collected under one cover and an analysis conducted. The quality of the existing data would be evaluated with respect to the spatial and temporal distribution with depth, and this evaluation could enhance the planning for future studies of currents in TOTO.

The data taken prior to May 1961 are of poorer quality because of the lack of adequate geographic positioning methods, or because the method of geographic positioning was not discussed in sufficient detail to permit proper evaluation. For example, the primary method used in tracking drogues was radar. Accuracy depended on the range as well as on weather conditions. After a landmark has once been identified, the bearing may be determined within one or two degrees and the range within 100 to 200 yards.[1] Other forms of navigation used in collecting the data included optical triangulation. However, in most cases this method was not reported in enough detail to assess the accuracy of the data.

Since 1961, the Decca Hi-Fix system[2], designed for short ranges of 30 to 40 miles, has been used. The Decca system is a phase-comparison system; coordinates are hyperbolic in form; and accurate phase measurement permits repeatability better than fou' yards, with a clear indication of change in position of one yard on the baseline.

Since the data used in this report were collected with a number of different current measuring devices, the data are partially analyzed according to the device used. Limitations as to the quality of the water current data are discussed from the viewpoints of the methods employed in obtaining the data, navigation accuracies, and spatial and temporal distribution with depth.

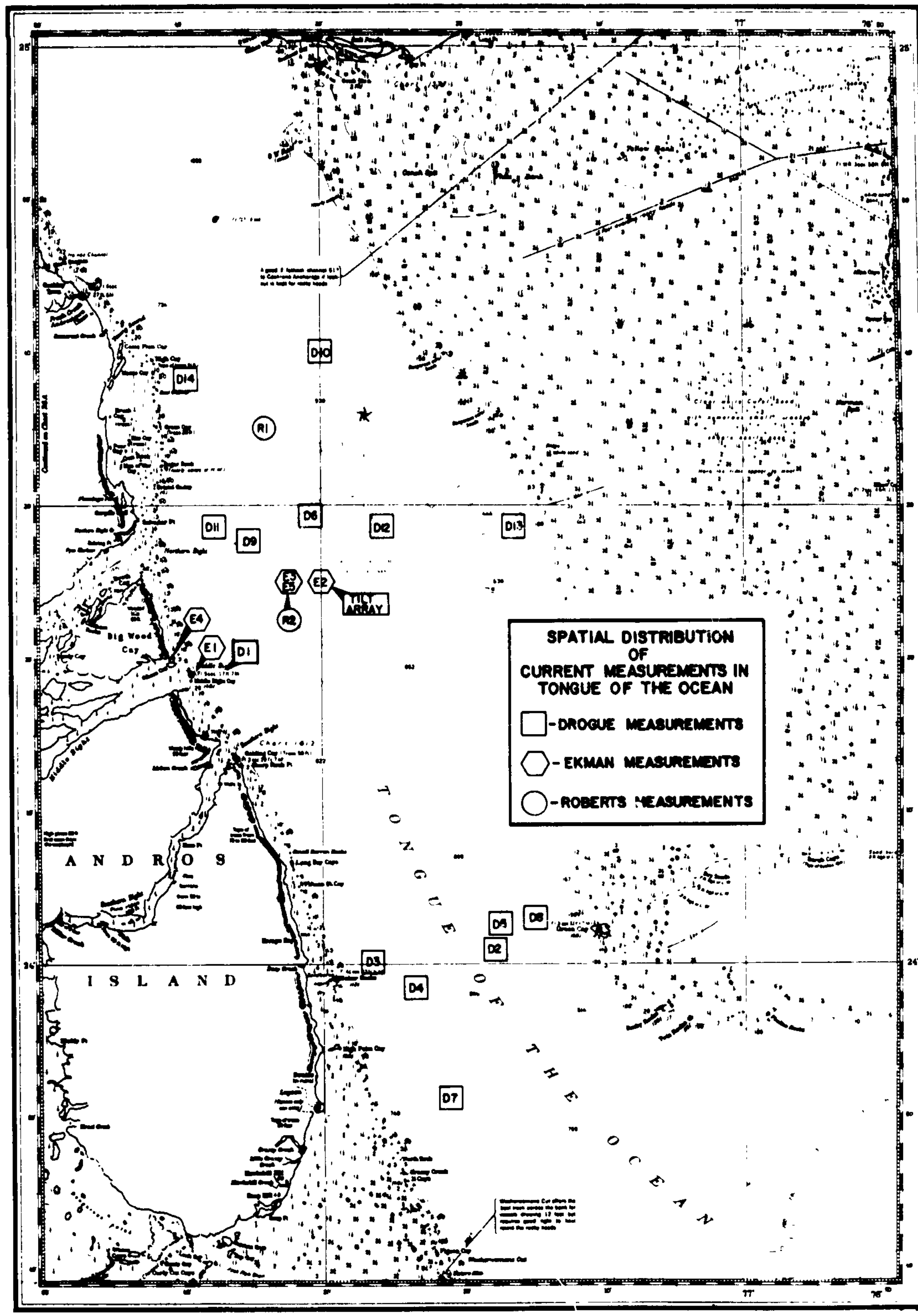
MEASUREMENT METHODS AND DEVICES

Methods

Measuring the motions of sea water can be divided into two categories, and each of these can be subdivided into two methods.

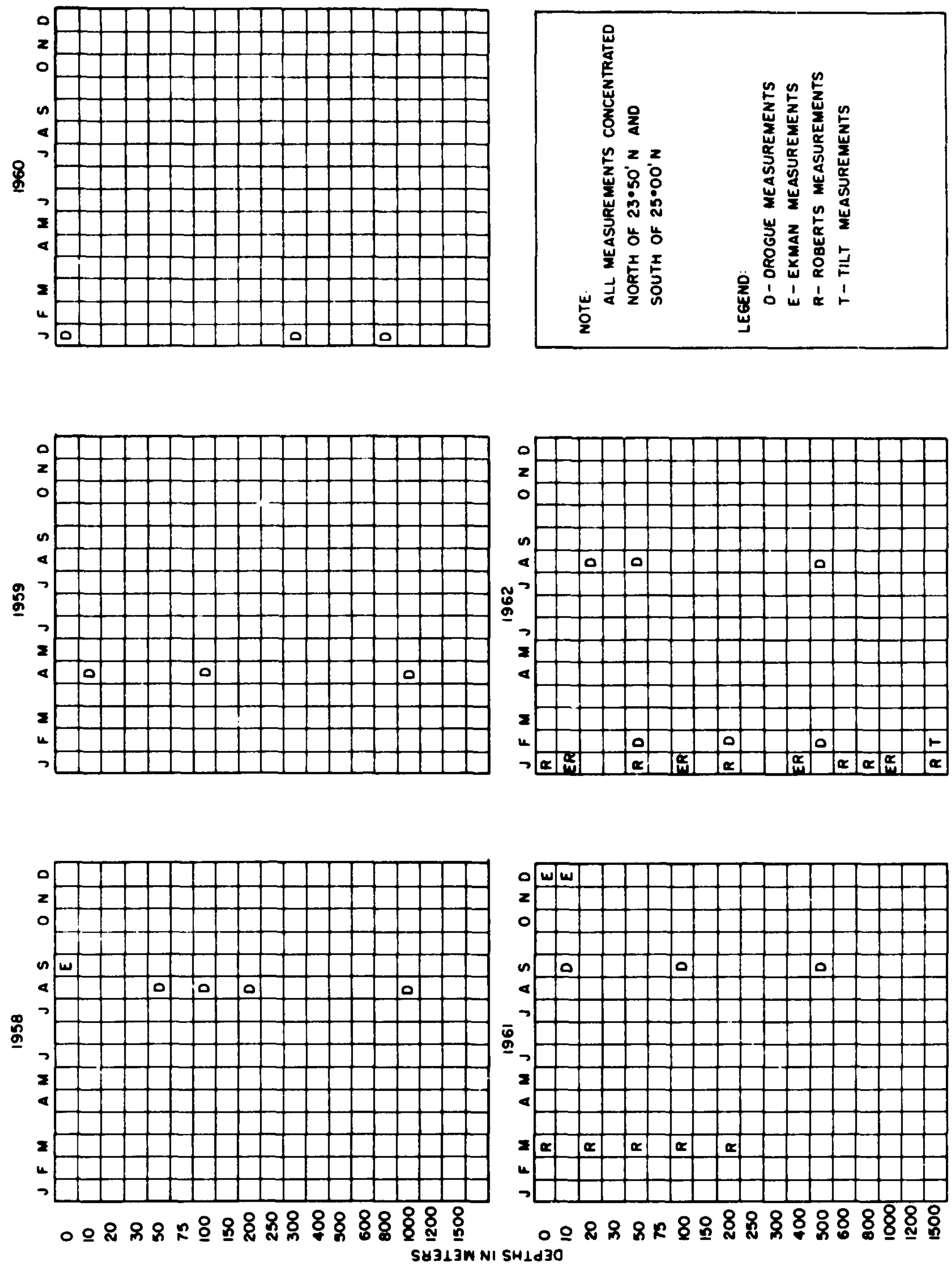
1. Direct Measurements.

a. The Eulerian method. The velocity of flow past a fixed geographical point is measured as a function of depth and time.



Spatial Distribution of Water Current Measurements Taken in TOTO

FIGURE 1



Temporal Distribution of Water Current Measurements Taken in TOTO

FIGURE 2

b. The Langrangian method. The trajectories of freely drifting devices at several depths in the water are plotted with respect to time.

2. Indirect Measurements.

a. The geostrophic method. The observed density distribution in the sea is used to estimate the horizontal component of the field of pressure.

b. The electromagnetic method. The gradient of electrical potential in the sea is associated with water motion through the earth's magnetic field.

All water current data taken in TOTO have been obtained through direct methods of measurement, and only these methods will be discussed in this report.

Devices

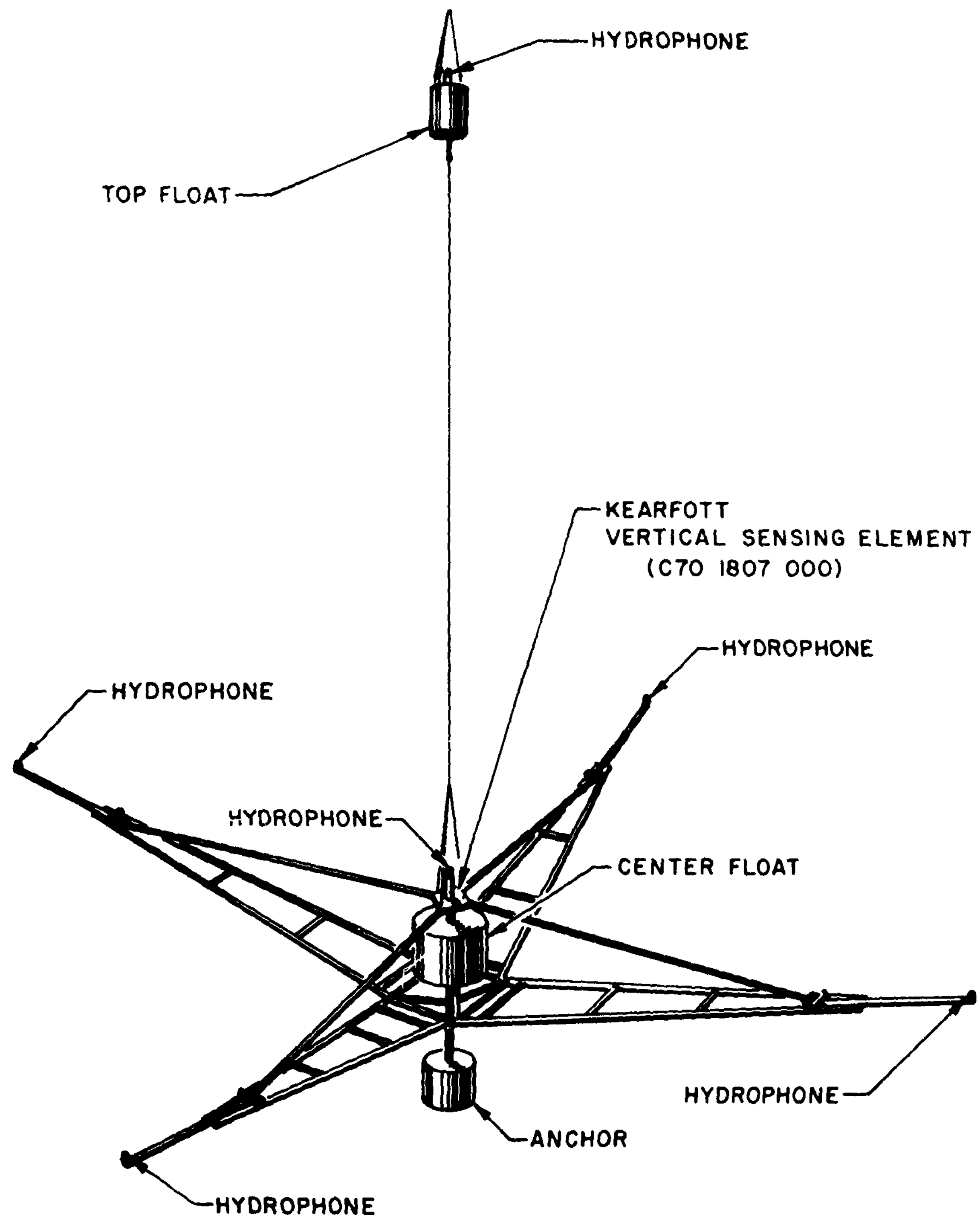
The devices that have been used in TOTO for the direct measurement of the currents are: the drogue[3], the Ekman current meter[4], the Roberts current meter[4], and a tilt device.[5]

1. Drogues (Lagrangian method) may consist of a metal or canvas cross, fish net, aviators parachute or other configuration that affords a large drag at the level of measurement compared with the drag on the rest of the system. Although there may be numerous variations in the type of surface float or sea anchor used in the construction of drogues, in most cases it is assumed that each drogue design will yield similar results. Both the canvas cross and the parachute type drogues were used in TOTO. With reference to the parachute drogue, Volkmann et al[3] report that the usefulness of the parachute drogue may be limited to depths where the current is more than 5 to 10 percent of the surface current.

2. The Ekman current meter (Eulerian method) is a mechanical device capable of measuring current speeds within a range of 0.1 to 1.5 knots. However, valid measurements cannot be made with an Ekman current meter unless the ship or buoy from which it is suspended is anchored.

3. The Roberts current meter (Eulerian method) is an electronic device capable of measuring current speeds within a range of 0.3 to 7.0 knots.[6] To obtain valid measurements, the ship or buoy from which it is suspended must be anchored.

4. The tilt device (figure 3) was designed specifically to track underwater vehicles, but had the supplementary ability to indirectly measure current velocity. Quite simply, the device formed a three-axis cartesian coordinate system, the drag of which is known.[5] Since the drag is known, the effect of the current would induce a tilt in the balanced array in the x-y direction. The resultant tilt is substituted into the emperical formula



Hydrophone Array Showing Placement of Tilt Device

FIGURE 3

$$V = 0.032\ (T)^{1/2}$$

where $T = \sqrt{T_x^{\ 2} + T_y^{\ 2}}$

and

V = current speed in knots

T = resultant tilt

T_x = x-component of tilt

T_y = y-component of tilt.

The current direction is scaled, using the tilt in x and the tilt in y, and is accurate to ±2 degrees.[5]

DISCUSSION OF DATA

Drogues

A majority of the water current data taken in TOTO were obtained with either parachute or cross type drogues. Spatial and temporal distributions of the measurements made with drogues are shown in figures 1 and 2, and all of the data are presented in Appendix A.

For purposes of this report, relative differences in measurements made with either the parachute or cross type drogues are considered to be negligible. In the following discussion, all measurements will be referred to as drogue measurements regardless of type used.

1. A series of drogue measurements were made by the Marine Laboratory of the University of Miami (MML)[7] from 19-22 August 1958. The drogues were set at depths of 50, 110, 200, and 1000 meters in three separate areas of TOTO (figure 1, areas D1, D2, D3). Due to the close proximity of the islands and cays, radar was used to obtain fixes on the surface floats of the drogues. MML reported that errors in obtaining radar fixes varied from ±0.04 to ±0.5 nautical miles, depending on target location. The drogue tracks are presented in Appendix A (figures A-1 through A-3). Water current speeds were obtained from the drogue tracks by finding the resultant of each track. That is, by connecting the start and end point (geographically) with a straight line, the mean direction can uniquely be determined, and, since time and distance are known, the speed can be computed. This method works quite well when the drogue tracks are uniform. However, if there are sharp turns, loops, and reversals, as are evident in some of the tracks, actual distances may be computed along the track as opposed to along the resultants. Such was the case with the 1000-meter drogue (figure A-2). Averages of the data obtained at areas D1, D2, and D3 are tabulated in table 1.

Table 1. Average of Drogue Speeds and Directions - TOTO August 1958

Area	Drogue Depth (meters)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction	Remarks
D1	110	9.5	3.8	NNW	Sharp turn
D2	50	13.0	4.7	S	-
	200	13.0	4.1	S	-
	1000	20.0	5.8	NNW, SSE	Complete reversal
D3	50	15.5	4.5	SSW	-
	200	6.5	4.5	SSE	Complete loop (anticyclonic)

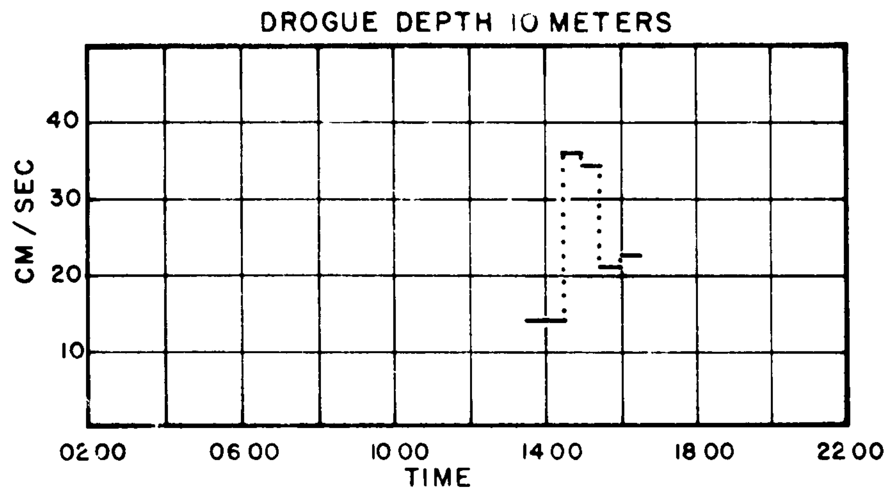
In general, the motion of the drogues appeared to follow the contours of the bank or land mass. However, irregularities in this directional motion, which may be attributed to inaccuracies in the radar navigational fixes, should be noted. The current speeds generally decreased with increasing depth in area D3, and increased with depth in area D2. The net flow of water was northerly in area D1 and southerly in areas D2 and D3. Although the track of the 1000-meter drogue in area D2 seems to indicate the presence of a tidal movement, this cannot be substantiated because the observation time was much less than that of one tidal period.

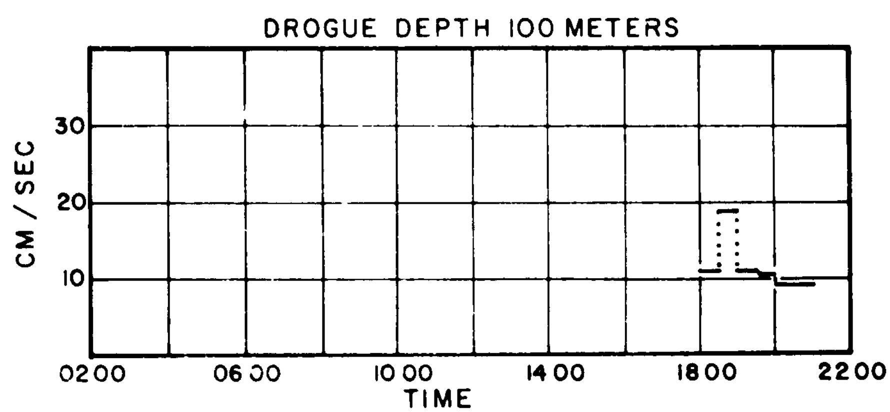
While nothing qualitative can be deduced from this data, a rather poorly defined anticyclonic circulation is suggested.

2. A series of drogue measurements were made by the U. S. Oceanographic Office (NAVOCEANO)[8] on 2-3 April 1959. The drogues were set at depths of 10, 100, and 1000 meters in three separate areas of TOTO (figure 1, areas D4, D5, D6).

The method used to obtain fixes on the surface floats of the drogues was not reported. Therefore, it is assumed that fixes were obtained either visually or with radar, since Decca Hi-Fix was not available at that time. Curves of speed versus time for each of the drogues set in areas D4 and D5 are shown in figures 4 and 5, and the drogue tracks are presented in Appendix A (figures A-4 through A-8). Current measurements obtained in area D6 were used to compute the frequency of occurrence of current speeds at various depths, and the data are presented in Appendix A (figure A-9).

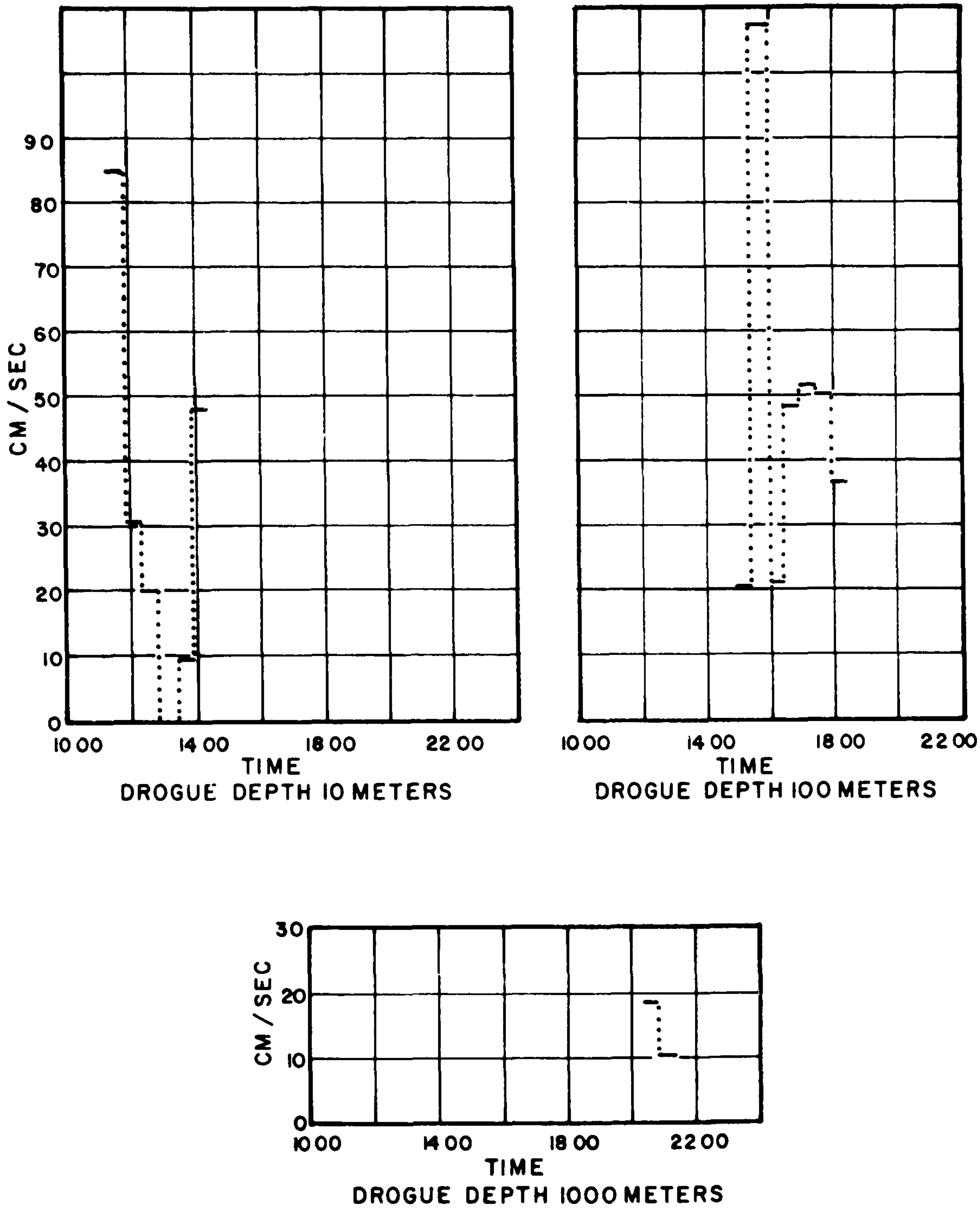
Averages of the data obtained at areas D4 and D5 are tabulated in table 2.





Current Speed vs Time - TOTO Area D4 - 3 April 1959

FIGURE 4



Current Speed vs Time - TOTO Area D5 - 2 April 1959

FIGURE 5

Table 2. Average of Drogue Speeds and Directions - TOTO April 1959

Area	Drogue Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction	Remarks
D4	10	36.0 - 14.0	23.0	3	SW	-
	100	19.0 - 9.5	11.7	3	SE	Sharp turn (cyclonic)
D5	10	87.5 - 0.0	32.8	3	NNW	Sharp turn (anticyclonic)
	100	107.0 - 20.0	47.8	4	WNW	Erratic course
	1000	18.5 - 10.5	14.5	1	ENE	Sharp turn northward

The mean motion of the drogues followed the contours of the banks with the exception of the 1000-meter drogue in area D5 which moved eastward for 0.5 hours and then northward for 0.5 hours.

The drogue tracks indicate a variability in both speed and direction. The maximum current speed was often twice or three times the minimum current speed, and the direction of the drogues changed markedly over short distances and periods of time.

Tidal movement might account for the variations in the speeds and directions of the drogues, but the observation time (approximately 1/4 tidal period) was not of sufficient duration so that any pronounced tidal movement might be noticed.

The net flow of water was southerly in area D4 which compares quite well with the net flow in area D3, measured by MML in August 1958. However, the net flow in area D5 was northerly which is opposite to the net flow measured in area D2 in August 1958.

3. A series of drogue measurements were made by Woods Hole Oceanographic Institution (WHOI)[9] in November 1959. The drogues were set at depths of 360 and 900 meters in two areas of TOTO (figure 1, areas D7 and D8). The method used to obtain fixes on the surface floats of the drogues, and the tracking times were not reported.

From previous measurements[8,10] it had been theorized that the currents in TOTO tended northerly on the western side and southerly on the eastern side. One of the purposes of this series of measurements was to determine, if possible, whether any general type of circulation prevailed in TOTO. For this reason the drogues were concentrated near the western and eastern sides of TOTO.

Averages of the data reported for areas D7 and D8 are tabulated in table 3.

Table 3. Average of Drogue Speeds and Directions - TOTO November 1959

Area	Drogue Depth (meters)	Average Speed (cm/sec)	Direction
D7	surface	25.5 - 51.5	S
	360	5 - 10	SE
	900	2.5	?
D8	360	10	N
	900	5	?

The data (table 3) suggest that the currents are cyclonic, moving in a direction opposite to that found the previous year (see table 1).

Generally, the current speeds decreased with increasing depth in areas D7 and D8.

4. A series of drogue measurements were made by MML[11] under contract to NAVOCEANO from 29 January to 3 February 1961. The drogues were set at depths of 50, 100, 250, 350, 500, 750, and 1000 meters in area D9 of TOTO (see figure 1). The drogue tracks are presented in Appendix A, figures A-10 through A-22.

Fixes on the surface floats of the drogues were made visually with a sextant, and a majority of the drogues were observed over an interval of time exceeding a full tidal period.

Observations taken of these drogues provided the following information:

a. 50-Meter Drogues. Three drogues (C, D, and E) were set for a depth of 50 meters, launched on 29 and 30 January 1961, and tracked for various times from 2.5 to 5.3 hours. The three drogues moved in a northerly direction at average speeds ranging from 16.5 to 29.5 cm/sec. The drogue tracks (figures A-10, A-11, and A-12), speeds, and directions were similar, indicating that the current flow was uniform at the 50-meter depth.

b. 100-Meter Drogue. Drogue L was set for a depth of 100 meters, launched on 2 February 1961, and tracked for about one day. The drogue moved generally in a NW direction at an average speed of 8 cm/sec. However, the drogue track (figure A-13) indicates sharp turns and in one place the drogue made a complete loop. It should also be noted that the maximum speed was 5 times greater than the minimum speed.

c. 250-Meter Drogues. Two drogues (J and K) were set for a depth of 250 meters, launched on 1 February 1961, and tracked for 8 and 24 hours respectively. Drogue J moved in a SSW direction at an average speed of 13 cm/sec. The maximum speed was 28 cm/sec and the minimum speed was 6.5 cm/sec. Drogue J seemed to be affected by turbulence because the direction changed 150 degrees and the speed doubled in a period of 1.5 hours (see figure A-14). Drogue K moved in a WSW direction at an average speed of 6.1 cm/sec. The track was more uniform and the maximum speed was 10 cm/sec while the minimum speed was 2.5 cm/sec (see figure A-15).

The tracks of these drogues indicate that there was little change in the current structure in this area over the period 1-2 February 1961, and the water current flow was generally SW.

d. 350-Meter Drogue. Drogue M was set for a depth of 350 meters, launched on 2 February 1961, and tracked for about 18 hours. The average speed was 7 cm/sec toward the NW, with a maximum speed of 10 cm/sec and a minimum speed of 5 cm/sec. The drogue track (figure A-16) was uniform in speed and direction, which indicates that a steady flow of current existed over the observation period.

e. 500-Meter Drogues. Three drogues (B, F, and I) were set for a depth of 500 meters. Drogue B was launched on 29 January 1961, and was tracked for about 10 hours. The drogue moved in a NE direction for about 4 hours then shifted direction to S at an average speed of 3.6 cm/sec (see figure A-17). The drogue nearly reversed direction, indicating a 135 degree change in current direction.

Drogue F, launched on 30 January 1961 and tracked for about 12 hours, followed a less erratic course than drogue B (see figure A-18). However, there is no explanation for the reversal of the direction of the drogue after launching. Again, there are great differences in the maximum and minimum speeds. In this case, the maximum speed of 46.5 cm/sec was nine times the minimum speed of 5 cm/sec. The average speed was 17.7 cm/sec, and the direction was toward the SSW.

Drogue I was launched on 1 February 1961 and tracked for about two days. Speeds were quite uniform, averaging 6.4 cm/sec with a maximum of 15 cm/sec and a minimum of 2.5 cm/sec. Directions were much less uniform. During the first half of the observation period, the drogue moved on an erratic course to the W; then it gradually turned toward the NNW and traveled on a more uniform course for the remainder of the time.

The three 500-meter drogues, observed over the period 29 January to 3 February, were very different in speed and direction. Averages of the data, tabulated in table 4, indicate that variability can take place in the water current structure at a given depth over a relatively small area and short period of time.

Table 4. Average Speeds and Directions of Drogues B, F, and I - TOTO, January-February 1961

Drogue	Depth (meters)	Range of Speed (cm/sec)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction	Remarks
B	500	5.0 - 2.5	3.6	10.4	NE; S	Sharp turn
F	500	46.5 - 5.0	17.7	12.4	SSW	Sharp turn
I	500	15.0 - 2.5	6.4	44.5	W; NW	Slow anticyclonic turning

f. 750-Meter Drogue. Drogue H was set for a depth of 750 meters and launched on 1 February 1961. Drogue H was tracked for about the same period of time and followed a course similar to drogue I (see figures A-19 and A-20). The average speed of the drogue was 6.9 cm/sec, with a maximum of 15 cm/sec and a minimum of 2.5 cm/sec. The speed of the current appeared to increase gradually from 5 to 10 cm/sec over the two-day observation period. From the similarity of the tracks of drogues H and I, it seems reasonable to assume that the current speed was uniform throughout the water column between 500 and 750 meters.

g. 1000-Meter Drogues. Two drogues (A and G) were set for a depth of 1000 meters, launched on 29 and 30 January, and tracked for 20.7 and 9.3 hours respectively. Drogue A moved at an average speed of 15.3 cm/sec. The maximum speed was 30 cm/sec and the minimum speed was 5 cm/sec. The drogue track (figure A-21) was so erratic that it is difficult to determine the mean flow with confidence. In addition to reversing direction, at one point the drogue turned clockwise closing on its own track in a one square mile area. However, this drogue track tends to show a tidal effect, in that the period of turning coincides with the tidal period.

Drogue G, unlike drogue A, moved in a westerly direction throughout the 9.3 hour observation period. The average speed was 5 cm/sec, with a maximum of 10 cm/sec and a minimum of 2.5 cm/sec. The track of drogue G (figure A-22) shows no erratic movements in direction or large fluctuations in speed, which indicates that the current flow was uniform.

The averages of the data obtained at area D9 are tabulated in table 5.

Table 5. Averages of Drogue Speeds and Directions - TOTO, January-February 1961

Drogue	Depth (meters)	Range of Speed (cm/sec)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction	Remarks
C	50	31.0 - 25.5	29.7	4.3	N	-
D	50	25.5 - 10.5	18.3	2.5	NNE	-
E	50	24.2 - 3.6	16.5	5.3	N	-
L	100	25.5 - 2.5	8.0	27.5	NW	Closed loop (anti-cyclonic) - sharp turn
J	250	28.0 - 6.5	13.0	8.0	SSW	Sharp turns
K	250	10.0 - 2.5	6.1	24.3	WSW	-
M	350	10.0 - 5.0	7.0	18.4	NW	-
B	500	5.0 - 2.5	3.6	10.4	NE;S	Sharp turn (anticyclonic)
F	500	46.5 - 5.0	17.7	12.4	SSW	Sharp turn (cyclonic)
I	500	15.0 - 2.5	6.4	44.5	W;NW	Slow (anticyclonic) turning
H	750	15.0 - 2.5	6.9	37.9	W;NNW	Slow (anticyclonic) turning
A	1000	30.0 - 5.0	15.3	20.7	-	Very erratic - complete loop (anticyclonic)
G	1000	10.0 - 2.5	5.0	9.3	W	-

In summary, the average speeds of the currents generally decreased with depth. The highest current speeds were found in the layer of water between the surface and a depth of 50 meters. At depths from 250 to 750 meters, the speed of the currents was quite uniform, but the direction ranged from WSW to NNW. At 1000 meters, the average speed of the current was lower and the direction was toward the west.

Maximum current speeds were 31 cm/sec at a depth of 50 meters, and 30 cm/sec at 1000 meters. In contrast, minimum speeds varied from 10 cm/sec at 50 meters to 2.5 cm/sec at 1000 meters. The net flow of water at the 50 meter depth was northerly while at the deeper depths it varied from WSW to NNW, primarily W and NW.

The tracks of drogues L, J. B, F, and A seem to indicate the presence of turbulence in the form of erratic movements, loops or reversals, and large variations between maximum and minimum speeds. A plot of the drogue speeds versus time indicates a periodic fluctuation corresponding closely to the semidiurnal tide period. While drogues A and B indicate this quite clearly, it is not as evident with drogues L, J, and F. However, a combination of the tidal current with the general current could result in the variations exhibited in these drogue tracks.

5. A series of drogue measurements were made by NAVOCEANO[12] 21-23 September 1961. The drogues were set at depths of 8, 100, and 500 meters in area D10 of TOTO (see figure 1). The drogue data are presented in Appendix A, table A-1. The Decca Hi-Fix navigation system was used to obtain the fixes on the surface floats of the drogues, and observations were made over an interval of time exceeding a full tidal period. Averages of the data obtained in area D10 are tabulated in table 6.

Table 6. Averages of Drogue Speeds and Directions - TOTO September 1961

Area	Drogue Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction
D10	8	37.0 - 7.0	9.5	25	SW
	100	35.0 - 1.5	8.0	24.7	NW,SW
	500	8.0 - 4.5	6.5	18.3	WSW,WNW

Current speeds generally decreased with increasing depth. The directions, however, were quite variable.

Tidal data, taken in the area of Fresh Creek, Andros Island in conjunction with this series of drogue water current measurements, are presented in table 7.

Table 7. Observed Tidal Data from Fresh Creek, Andros Island

Date	High	Low	Range (ft)
9/21/61	0410* 1640	1010 2300	2.8 2.8
9/22/61	0500 1750	1115 2350	2.9 3.2

*All times local EST.

When the times of the changes in the speeds of the drogues (figure 6) are compared with the tidal data, it is difficult to ascertain whether the changes in current speed can be attributed to the tidal motion. Based only on variations in the current speed, the tracks of the 8- and 500-meter drogues do not appear to exhibit tidal motion. On the other hand, the track of the 200-meter drogue does suggest, rather poorly, that the current is tidal in nature. Although these drogues were tracked for a period of time exceeding the tidal cycle, it was not sufficient to definitely show that the current structure was tidal in character.

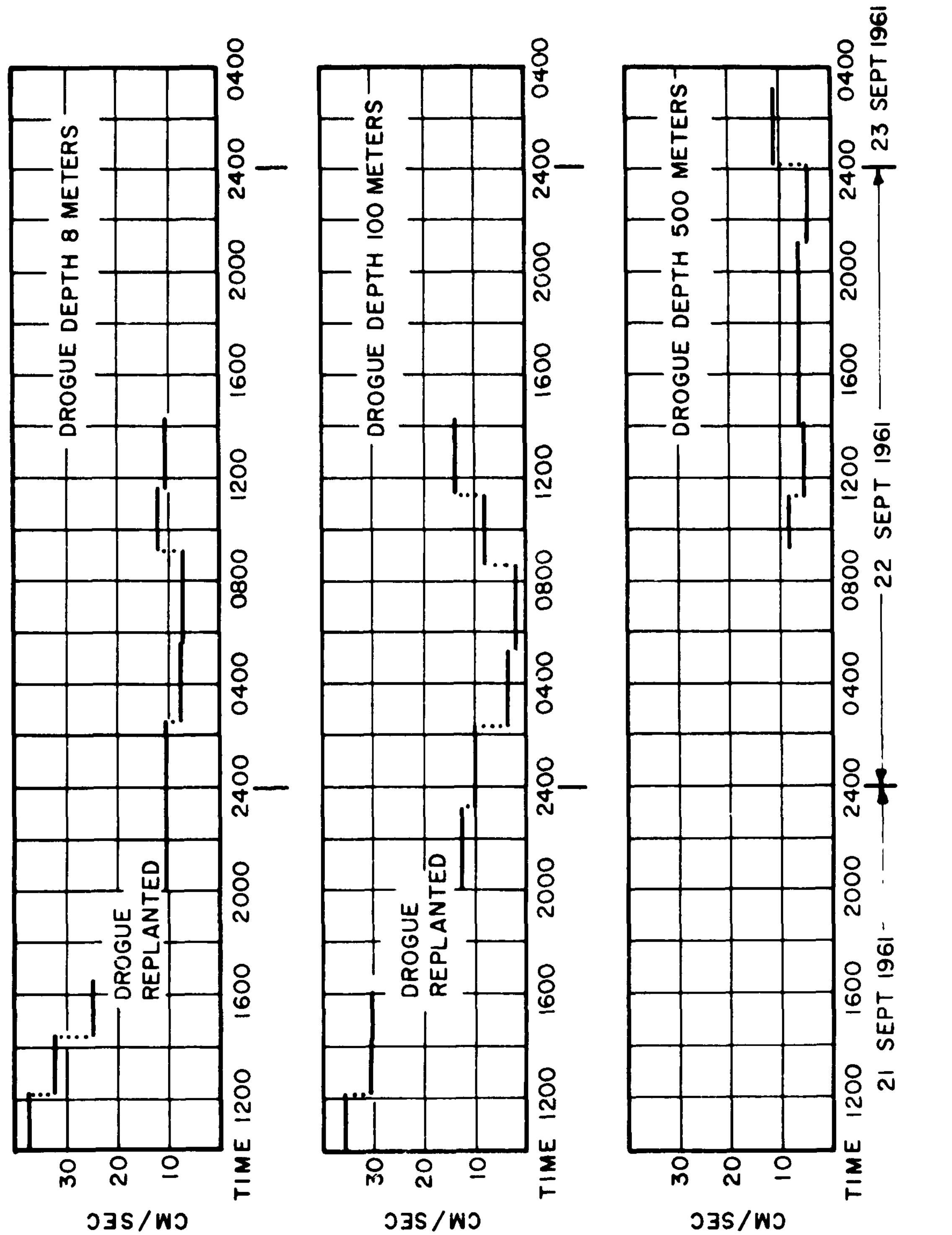
6. A series of drogue measurements were made by WHOI[13] from 1 to 10 February 1962. The drogues were set at depths of 50, 200, and 500 meters in three separate areas in TOTO (figure 1, areas D11, D12, and D13). The Decca Hi-Fix navigation system was used to obtain fixes on the surface floats of the drogues, and observations were made over an interval of time exceeding a full tidal period.

Curves of speed versus time for each drogue are shown in figures 7, 8, 9, and 10, and the drogue tracks are presented in Appendix A, figures A-23 through A-32.

Observations taken of these drogues provided the following information:

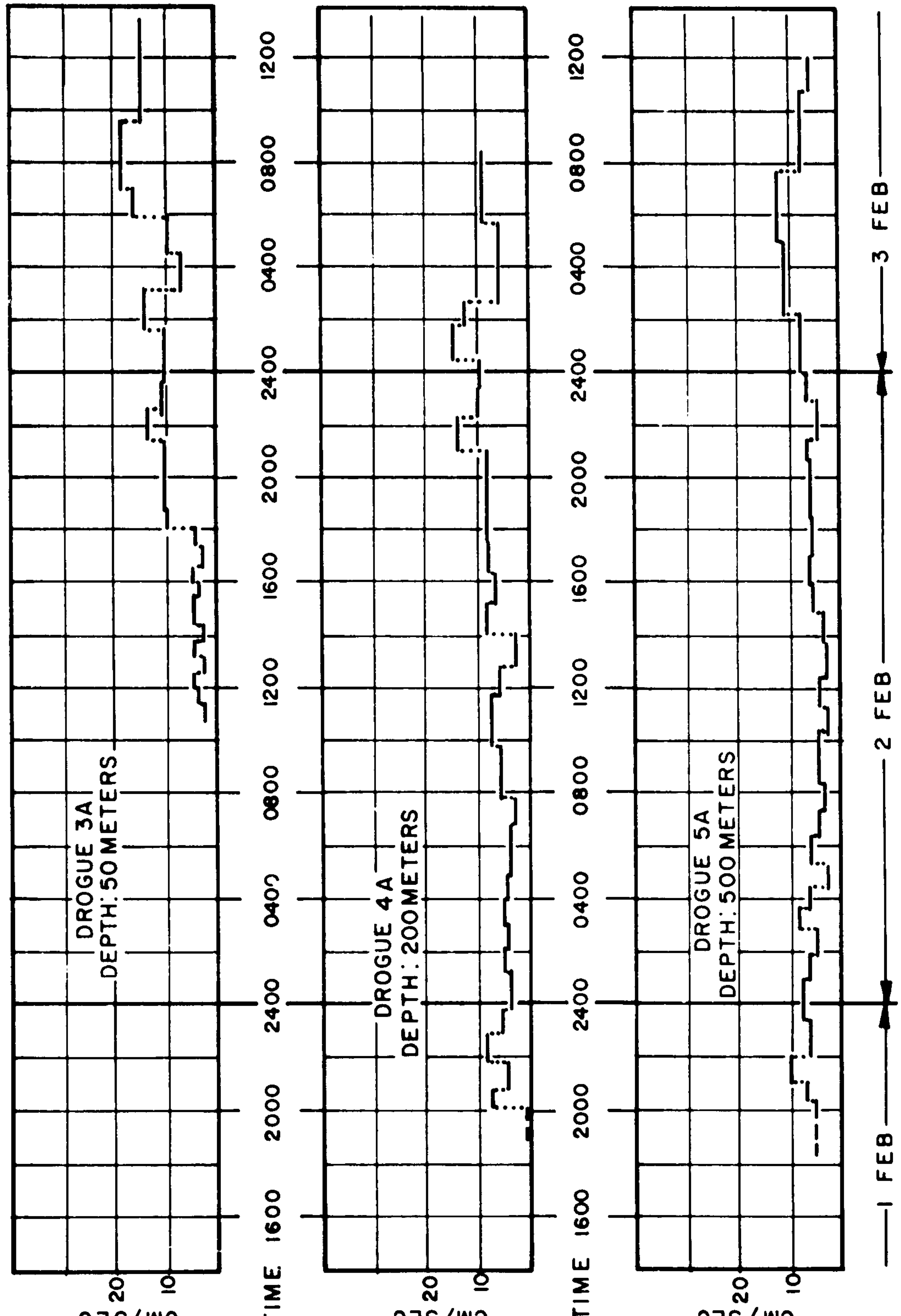
a. <u>50-Meter Drogues.</u> Drogue 3A was set in area D11 on 2 February 1962, and drogue 3B was set in area D12 on 7 February 1962. Both drogues were tracked for about 30 hours, and the tracks (figures A-23 and A-24) show a uniform movement toward N at an average speed of 8.2 cm/sec and a maximum speed of 18.1 cm/sec.

Drogue 3C, which was set in area D13 on 4 February and tracked for about 40 hours, moved SE for a period of about 14 hours, veered E, and then moved N for the remainder of the observation period (see figure A-25).



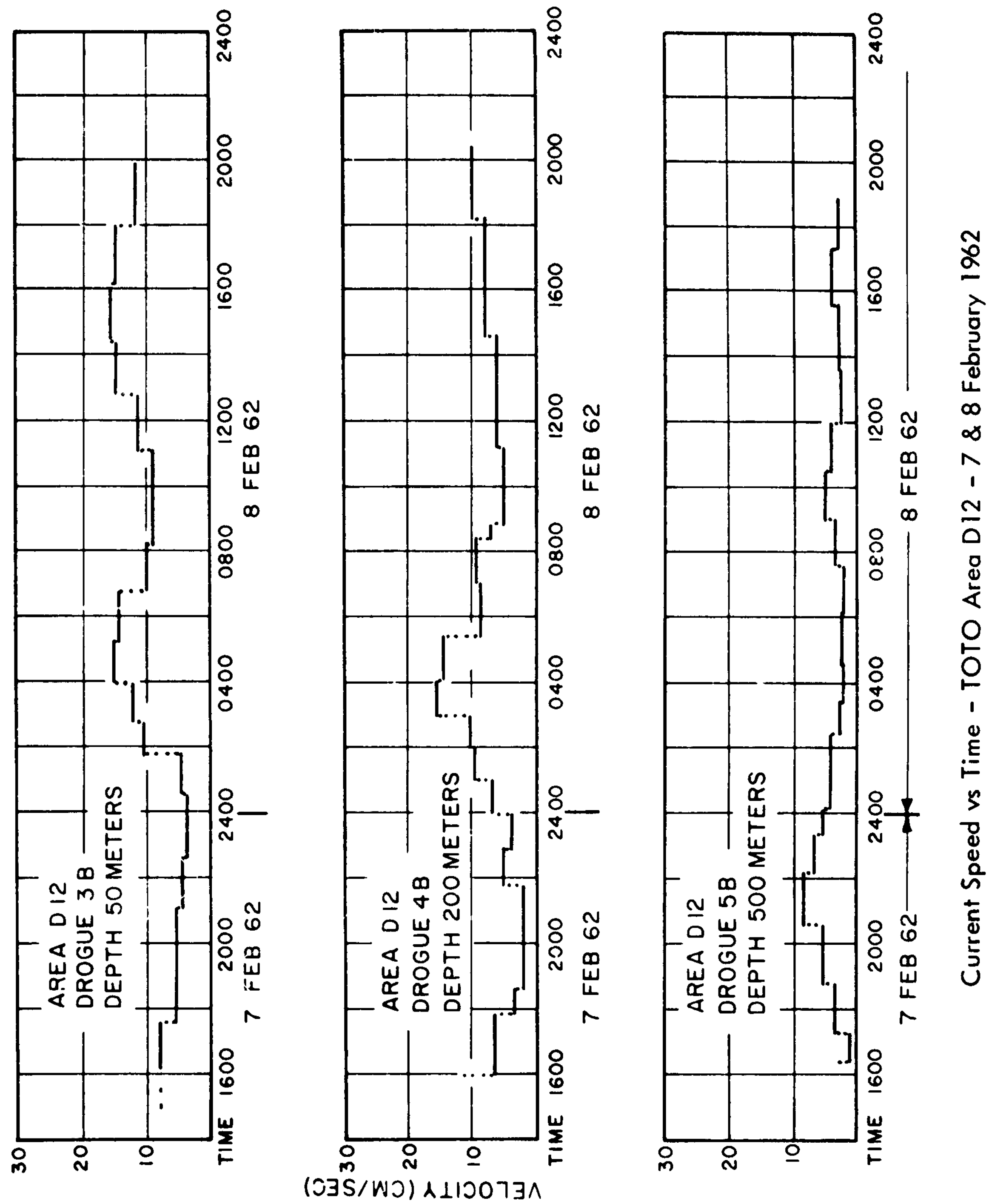
Current Speed vs Time - TOTO Area D10 - 21 to 23 September 1961

FIGURE 6



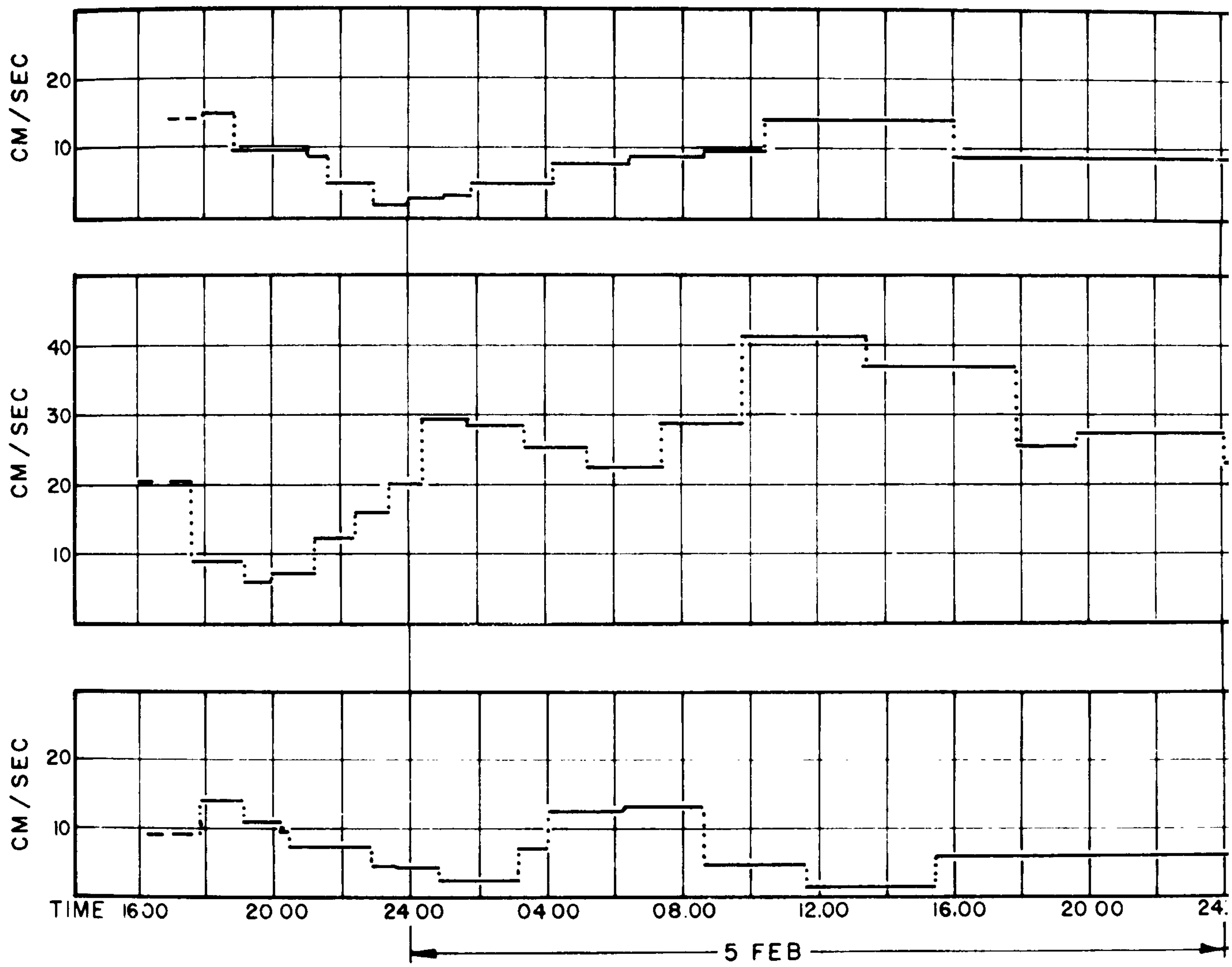
Current Speed vs Time - TOTO Area D11 - 1 to 3 February 1962

FIGURE 7



Current Speed vs Time - TOTO Area D12 - 7 & 8 February 1962

FIGURE 8

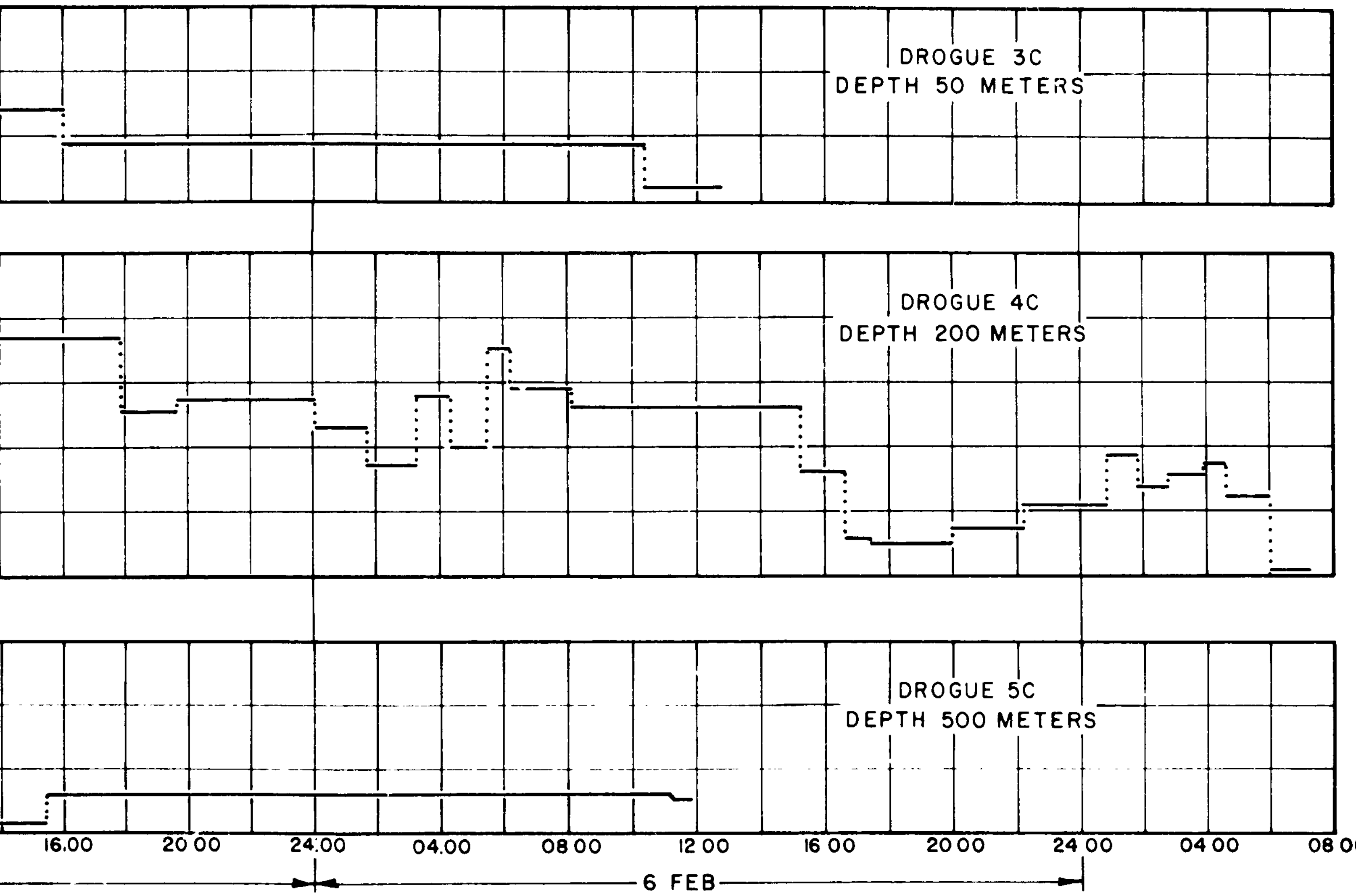


1

Current Speed vs Time - TOTO Area

FIGURE 9

2



Speed vs Time - TOTO Area D13 - 4 to 7 February 1962

b. <u>200-Meter Drogues</u>. Drogue 4A was set in area D11 on 1 February 1962, and drogue 4B was set in area D12 on 7 February 1962. Both drogues were tracked for more than one day, and the tracks (figures A-26 and A-27) show a relatively uniform movement toward NNW and N. The average speed of these drogues was 7.4 cm/sec, and the maximum speed was 14.9 cm/sec.

Drogue 4C, set in area D13 on 4 February 1962, was tracked for about 2 1/2 days. This drogue moved rapidly toward the NW at an average speed of 19.2 cm/sec, and had a maximum speed of 41.9 cm/sec (see figure A-28).

Because of this apparent "high speed" current at a depth of 200 meters, three more drogues (6C, 7C, and 8C) were set in area D13 on 9 February, and tracked for about 24 hours. The variations in the speeds and the anticyclonic movements of these drogues (figure A-29) seem to indicate the presence of some turbulence. In any case, the high speed current indicated by the track of drogue 4C was no longer present.

c. <u>500-Meter Drogues</u>. Drogue 5A was set in area D11 on 1 February 1962, and tracked for about 45 hours. Drogue 5A moved toward the N for about 13 hours, veered to SW, and then S for the remainder of the observation period (see figure A-30). The average speed was 6.2 cm/sec, and the maximum speed was 11.7 cm/sec.

Drogue 5B, set in area D12 on 7 February 1962, was tracked for about 30 hours. This drogue moved S (figure A-31) at an average speed of 3.9 cm/sec, and had a maximum speed of 8.9 cm/sec.

Drogue 5C was set in area D13 on 4 February and tracked for about two days. The track (figure A-32) shows that the drogue moved SSE at an average speed of 7.5 cm/sec and at a maximum speed of 12.6 cm/sec.

Averages of the data obtained at areas D11, D12, and D13 are tabulated in table 8.

Table 8. Average of Drogue Speeds and Directions - TOTO, February 1962

Area	Drogue Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/Sec)	Total Tracking Time (hours)	Direction	Remarks
D11	50	18.1 - 2.2	7.8	28.8	N	-
	200	14.3 - 2.5	6.6	38.0	W;NNW	Gradual turn (anticyclonic)
	500	11.7 - 3.1	6.2	45.1	N;S	Cyclonic turning
D12	50	15.2 - 0.9	9.3	31.9	N	-
	200	14.9 - 2.3	8.1	32.3	NNW	-
	500	8.9 - 1.1	3.9	30.7	S	-
D13	50	14.6 - 1.6	7.6	44.0	S;N	Cyclonic turn
	200 - 5C	41.9 - 1.1	19.2	62.2	NW	High speed
	200 - 6C	7.2 - 0.4	4.1	24.8	NW	Anticyclonic turn
	200 - 7C	8.7 - 1.2	3.8	25.0	NW	Anticyclonic turn
	200 - 8C	10.9 - 0.4	4.3	17.0	N	-
	500	12.6 - 1.6	7.5	43.0	SE	-

In summary, the speed of the currents decreased with increasing depth, and the flow of water was toward N at the 50- and 200-meter depths and toward S at a depth of 500 meters. The high speed current at a depth of 200 meters in area D13 appears to be a non-steady, quasi-permanent type current, since it either moved in geographical position or ceased to exist. The explanation for this current is not known.

If these data can be construed as representative of the currents in TOTO, then the general circulation of the waters in TOTO is unlike that previously hypothisized.[5, 13]

7. A series of drogue measurements were made by Marine Acoustical Services Inc.[14] of Miami, Florida on 22-23 August 1962. The drogues were set at depths of 15, 46, and 457 meters in area D14 of TOTO (see figure 1). The drogue data are presented in Appendix A, figures A-53 through A-55. Fixes on the surface floats of the drogues were obtained with the Decca Hi-Fix navigation system. Averages of the data obtained in area D14 are tabulated in table 9.

Table 9. Averages of Drogue Speeds and Directions - TOTO, August 1962

Area	Drogue Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Tracking Time (hours)	Direction
D14	15	40.6 - 11.6	22.4	6.75	SW-W
	46	14.5 - 10.3	12.9	6.75	SW
	457	7.9 - 2.9	5.3	30.8	SW

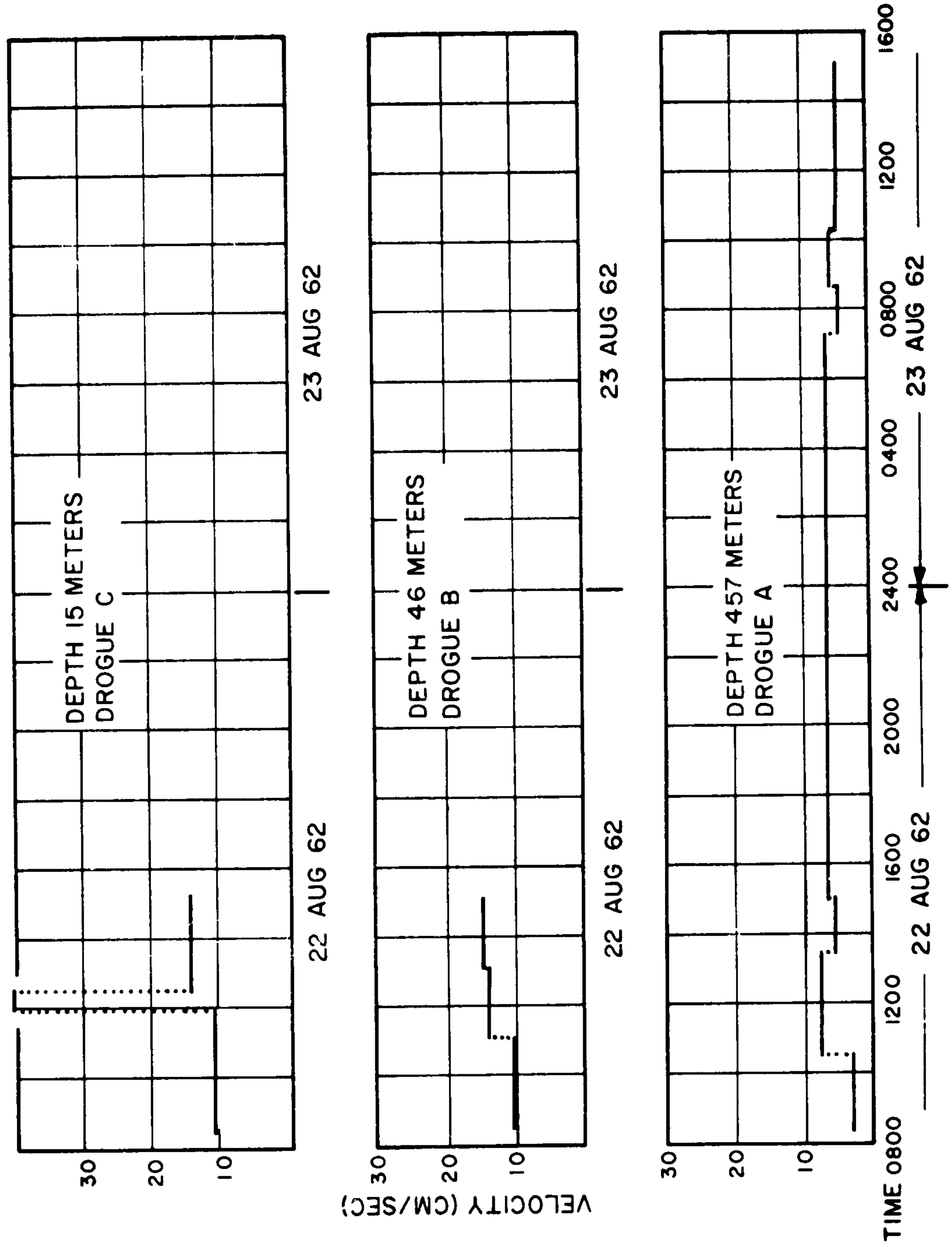
In general, current speeds decreased with increasing depth. However, the net flow of water was toward the SW (toward the banks as opposed to along the bank contours).

The range of current speeds was greater at the 15 meter depth than at 46 or 457 meters, indicating a greater variability in the speeds of the current near the surface (15 meters) than at the other depths.

Only one of the drogues was tracked long enough to determine whether the currents were tidal in nature. The speed versus time plot of this drogue (figure 11) failed to show fluctuations in the current speed comparable in time with that of the tidal cycle.

Ekman Current Meters

Since August 1958, Ekman current meters have only been used for about 45 hours to take measurements of the water currents in TOTO. The meters used to take these measurements have been suspended from ships anchored in three-point or single-point moors, except one where the meter was suspended from an anchored barge in Middle Bight. The measurements have been made at various depths from 3 to 1000 meters, and at various locations along the banks and in the deep waters of TOTO (see figure 1, areas E1, E2, E3,



Current Speed vs Time - TOTO Area D14 - 22 & 23 August 1962

FIGURE 11

E4, and E5). The data obtained are tabulated in Appendix B.

For this discussion, the data are broken down into two categories: measurements taken along the banks in shallow water, and measurements taken in deep water.

1. Shallow water current measurements (along the banks).

a. On 21 August 1958, MML[7] made a series of measurements on the outer edge of the reef at Middle Bight (area E1, figure 1). The Ekman current meter* was suspended from the ship to a depth of three meters, and the ship was anchored in a single-point moor.

Figure 12A is a vector diagram of the water current observations, and the data obtained are tabulated in table B-1, Appendix B. The directions of the current are shown on the diagram, and the length of each vector represents the speed. From 0900 to 1230 the direction of the current was generally toward the SW. After 1230, the direction of the current veered gradually to the W, then somewhat more abruptly toward the N, and there was a definite change in the speed. The maximum speed was 20.64 cm/sec and the minimum was 9.05 cm/sec.

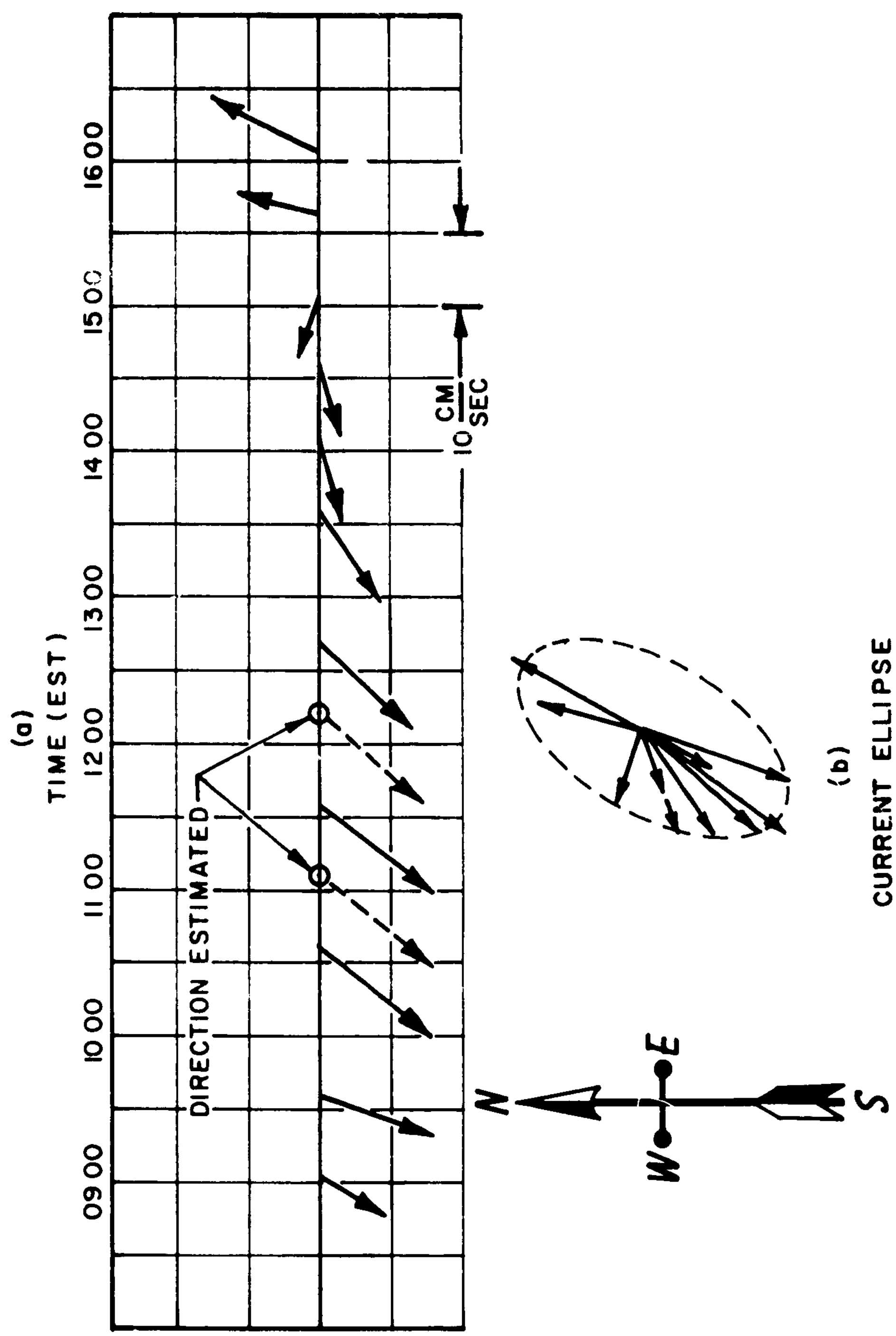
These data seem to indicate the presence of a major current component which is semidiurnal in character and tidal in nature, with an amplitude of ~16 cm/sec. If the time axis is reduced to a point (figure 12B) and the vectors are plotted in the same sense as before, the vectors form an ellipse, the major axis of which indicates a change in the direction of flow comparable to the tidal motion.

b. On 7 December 1961, NUOS made a series of measurements in Middle Bight (area E4, figure 1). An Ekman current meter was suspended from an anchor barge, and the measurements were taken to study the tidal currents passing through Middle Bight. Figure 13 is a vector diagram of the currents observed, and the data obtained are tabulated in table B 2. The maximum current speed was 96 cm/sec. From the changes noted in the direction of the flow, the current was semidiurnal in character.

2. Deep water current measurements (all taken by NUOS).

a. A series of measurements were made on 6 December 1961 in area E2 (see figure 1). The research vessel SWAN was anchored in a three point moor, and an Ekman current meter was lowered to different depths. Wind velocities were measured at the same times as the current, using a Bendix Friez aerovane in conjunction with the ship's heading on the moor. It should be noted that the heading of the SWAN ranged from 068° to 069°, indicating the relatively high degree of stability of the three-point moor.

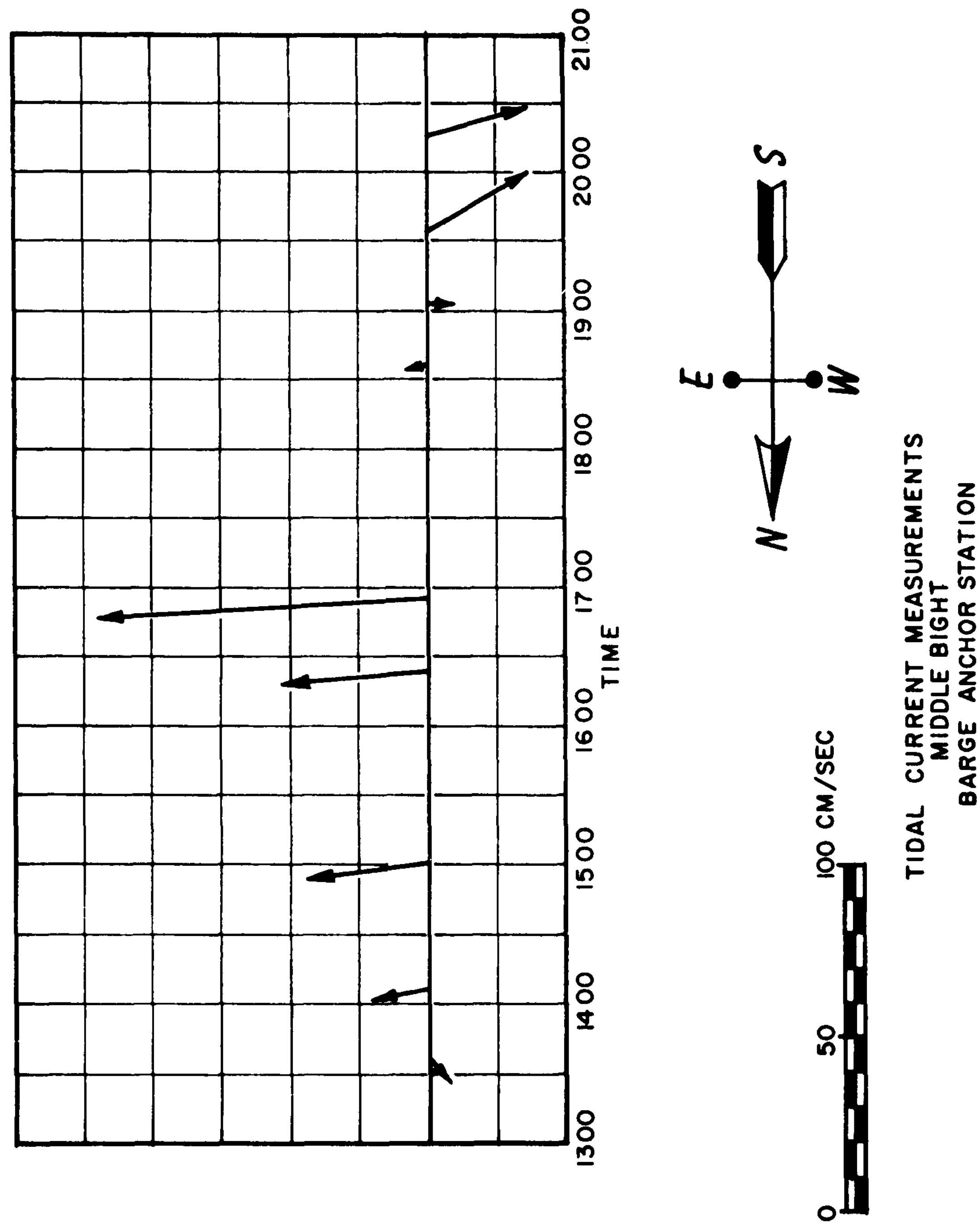
*MML reported that the Ekman meter used to take these measurements was in error by 10 percent.



DEPTH: 3 METERS

Current Velocity vs Time - TOTO Area E1 - 21 August 1958

FIGURE 12



Current Velocity vs Time - TOTO Area E4 - 4 December 1961

FIGURE 13

Figure 14 is a vector diagram of both the water current and wind observations. The first four current measurements were taken within 30 meters of the surface. The current speed ranged from 3 to 7 cm/sec with a 90 degree change in direction over the time interval of three hours. The fifth measurement, taken at a depth of 305 meters, showed a complete reversal in the direction of the current from that of the first measurement. However, the speed of the current was about the same. The data obtained from these observations are tabulated in table B-3.

The data indicate the presence of a major current component that is not wind driven at shallow depths, appears to be tidal in nature, and is relatively uniform in speed to a depth of at least 300 meters.

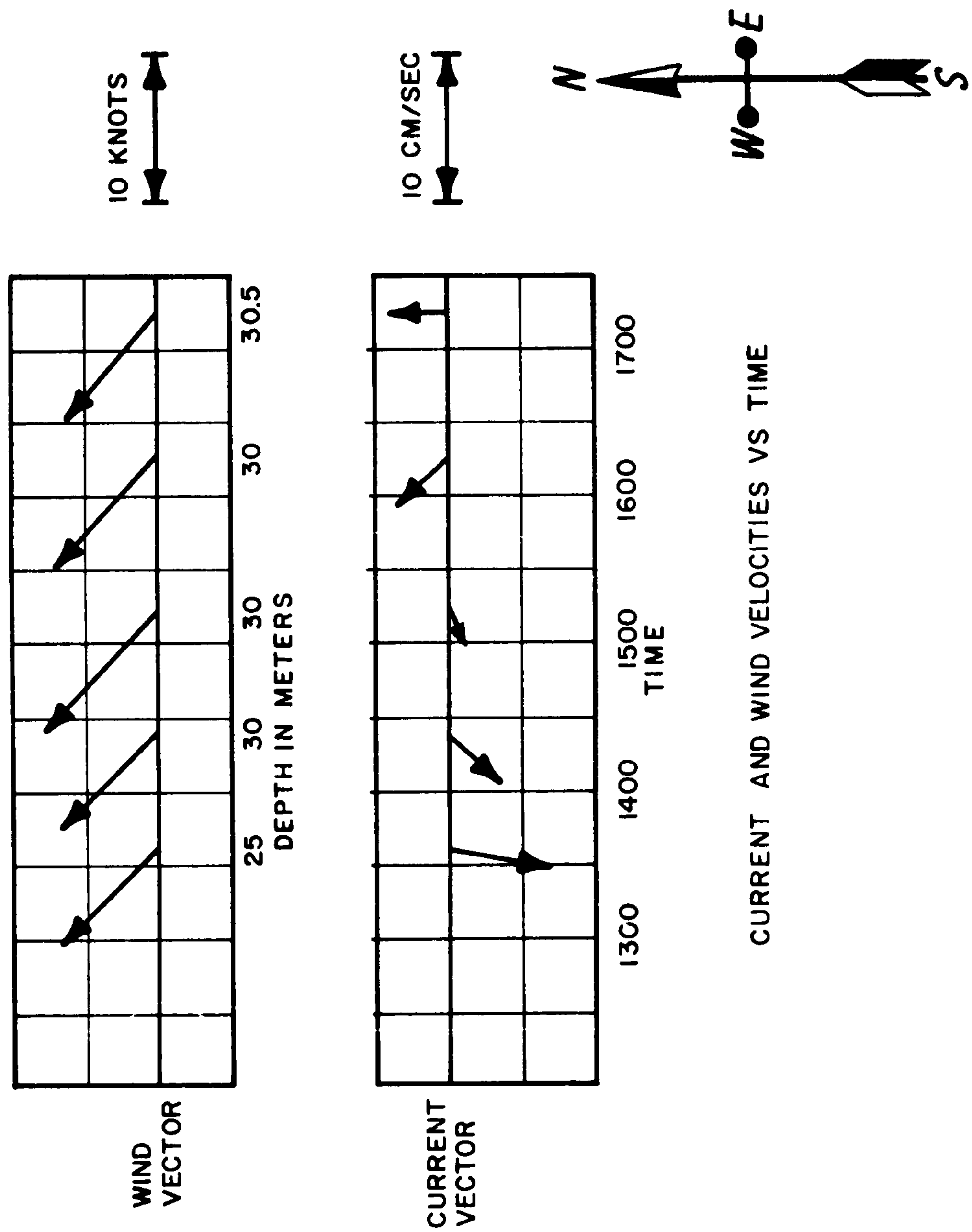
b. Another series of measurements were made on 12-13 December in area E3 (see figure 1). The research vessel LORD RAYLEIGH was anchored in a single-point moor. Two Ekman current meters were used; one was lowered off the bow and the other from the stern of the vessel. Twelve measurements were taken at the stern at a depth of 12 meters, and four measurements were taken at the bow at various depths from 30 to 285 meters. Figure 15 is a vector diagram of the water current observations; the top row shows the directions and speeds at the 12-meter depth and the bottom row shows the directions and speeds at the deeper depths. The data obtained are tabulated in table B-4.

Although no measurements were made due to the lack of aerovane equipment, the direction of the wind was from the southeast. While the direction of the current flow varied at the deeper depths, it was, in general, opposed to the direction of the wind at the shallow depth.

The data indicate a weaker current at the deeper depths. This may be due to a damping effect on the vertical accelerations of the meter caused by the catenary in the cable from which the current meter was suspended.

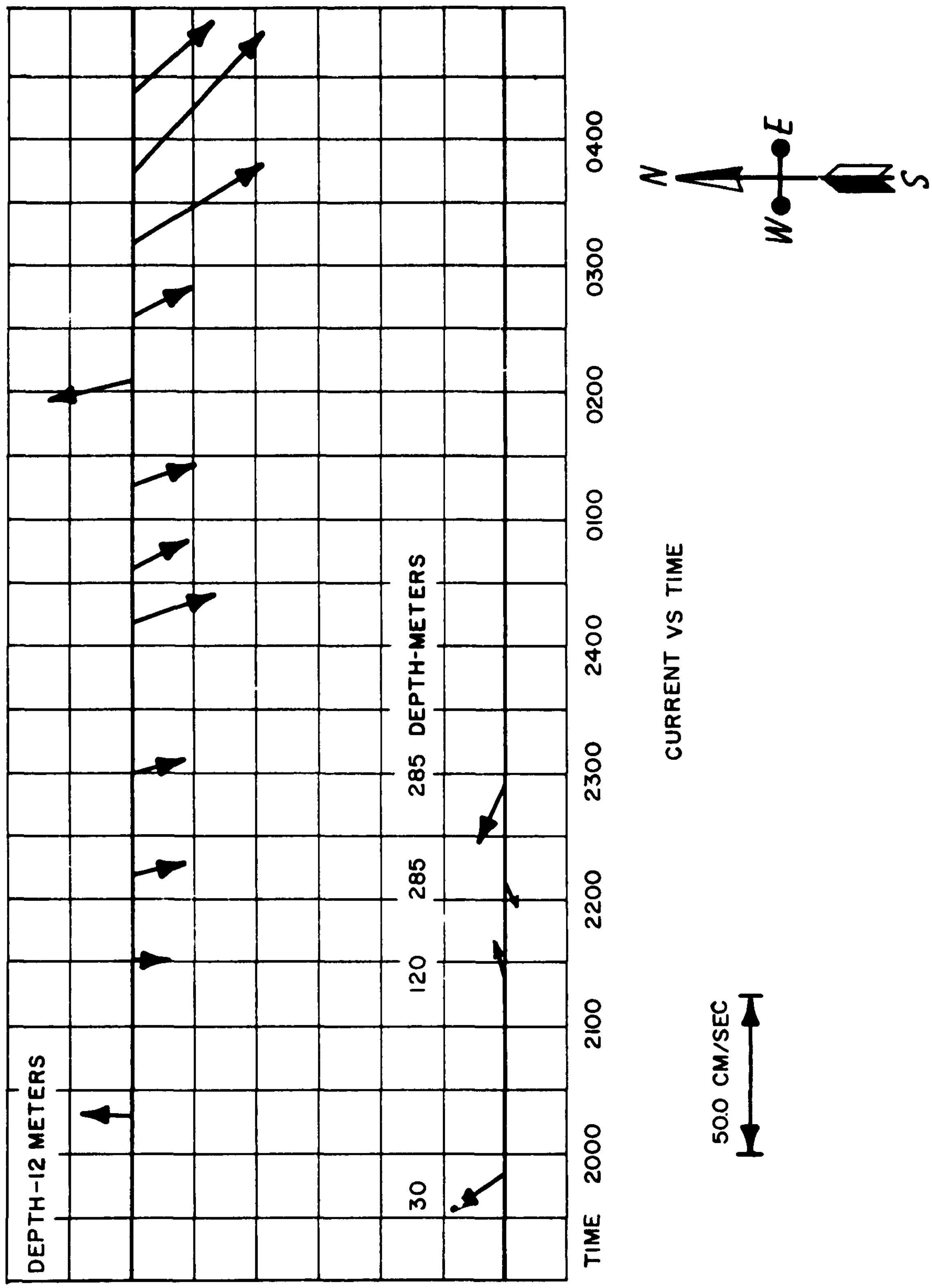
c. A series of measurements were made on 31 January 1962 in area E5 (see figure 1). The research vessel H. C. HAYES was anchored in three point moor, and an Ekman current meter was used to take water current measurements at depths of 10, 100, 400, and 1000 meters.

Figure 16 is a vector diagram showing the directions and speeds of the water current at each depth. The data obtained are tabulated in table B-5. At the 10-meter depth, the direction of the current was toward the north at a maximum speed of 11.4 cm/sec and a minimum speed of 8.3 cm/sec. At 100 meters, the current flow was toward the NW, veering to the W, and the speed decreased from 9.2 to 0.8 cm/sec. At the 400- and 1000-meter depths, the current was weak and variable, with the exception of one observation where a current speed of 6.6 cm/sec in a N direction was recorded.



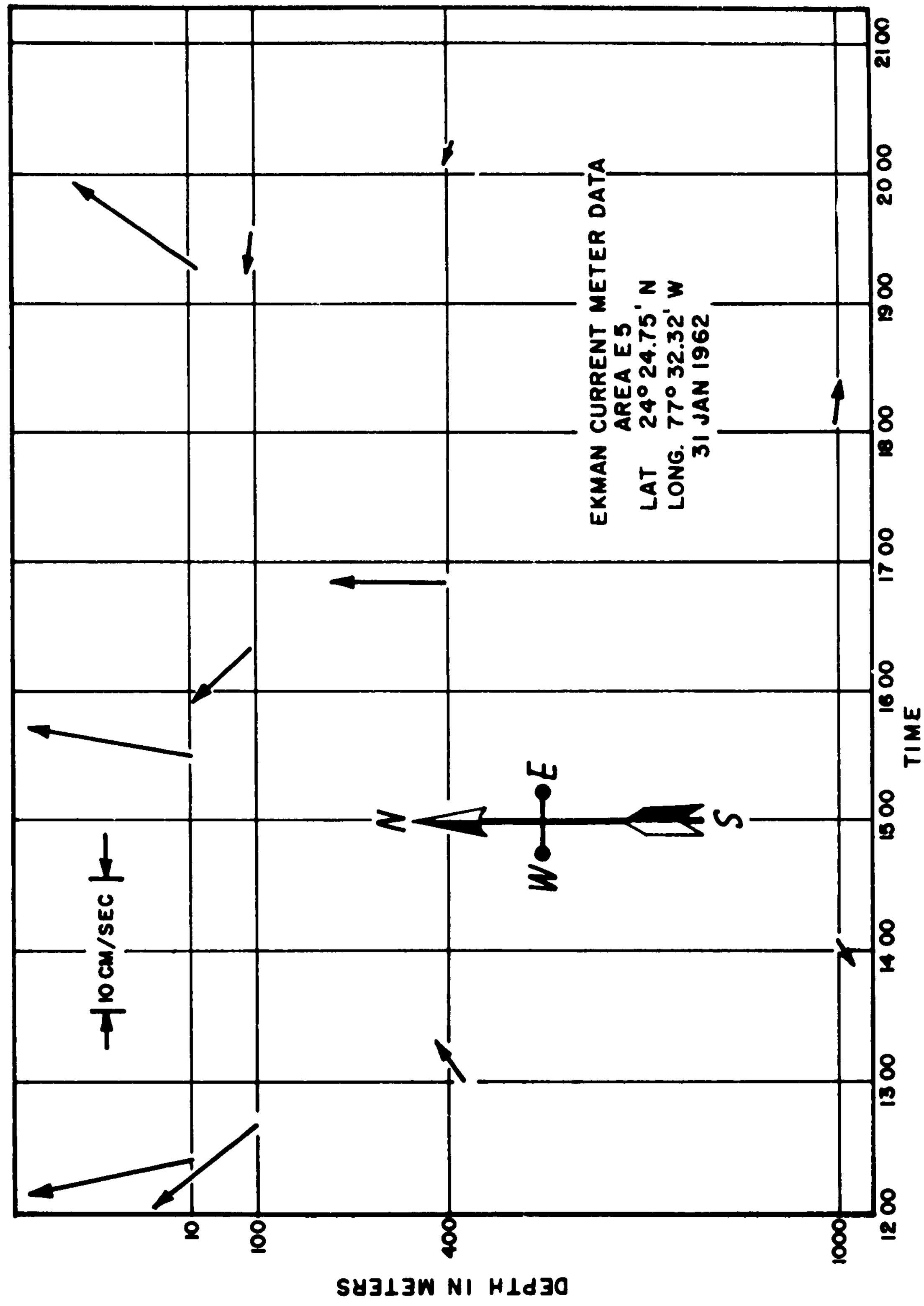
Current and Wind Velocities vs Time - TOTO Area E2 - 6 December 1961

FIGURE 14



Current Velocities vs Time - TOTO Area E3 - 12 & 13 December 1961

FIGURE 15



Current Velocities vs Time - TOTO Area E5 - 31 January 1962

FIGURE 16

In general, the current speed decreased with increasing depth, and the direction of the flow was N to NW in the upper 100 meters of the water column and variable at the deeper depths.

Ekman current meters are balanced in such a way that vertical or horizontal movements cause the counters to record in the same manner as a flow of water through the meter. In a discussion of the use of current meters from anchored ships, Von Arx[4] shows the complex motions of a ship anchored in a single-point moor (see figure 17). There are only short intervals (points A, B, C, and D, figure 17) where there is no effective motion of the vessel. The stability of a ship anchored in a three-point moor will be better. This is illustrated by the fact that the headings of the SWAN remained within a range of one degree.

From these considerations, it appears that water current data taken from a ship anchored in a single-point moor would be biased toward a stronger current indication. This would be more evident at shallow depths where the catenary in the cable suspending the current meter would have little or no damping effect on vertical accelerations.

Roberts Current Meter

NAVOCEANO[10] used Roberts current meters to make a series of water current measurements in TOTO during the period 9 to 14 March 1960. A ship was anchored in a three-point moor in area R1 (see figure 1), and measurements were taken at depths of 10, 25, 50, 75, 100, 150 and 200 meters.

The data obtained (see Appendix C, table C-1) indicate that:

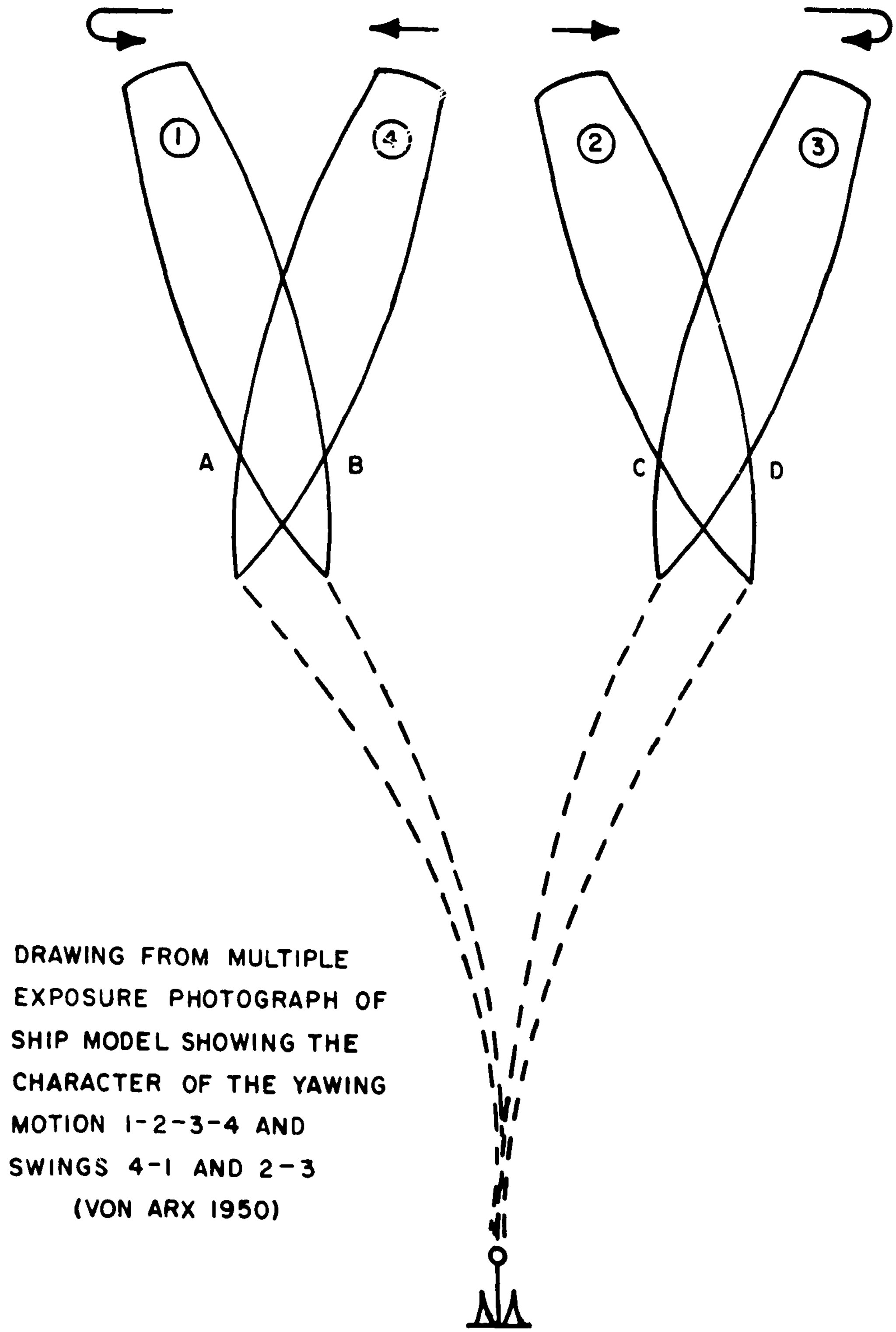
The current gradient from 10 to 100 meters averaged 0.2 knots with a range of 0.01 to 0.80 knots.

The current speed at 10 meters averaged 0.5 knots with a range of 0.00 to 1.00 knots.

The prevailing current direction from 10 to 100 meters was NE with an average variation of 40° and a range of 160°, the difference decreasing as the wind persisted in one direction.

The maximum current observed was one knot setting SE during a NE wind whose speed increased from 16 to 23 knots in 4 hours.

Below 100 meters, the current averaged about 0.30 knots with a range from 0.20 knots (the probable lower limit of the meter) to 0.51 knots during the first day of observation. During the remainder of the observation period the current averaged about 0.40 knots with a range of 0.20 knots to 0.60 knots. The direction varied from NNE to SE.



Ship Motion from a Single-point Moor

FIGURE 17

The maximum current shear observed from 10 meters to 200 meters was 0.65 knots when the speed of current at 10 meters was 1.00 knots and the speed of the current at 200 meters was 0.35 knots.

The average current speeds and ranges of current speeds are presented in table 10.

Table 10. Average Speed and Direction of Currents - Area R1 TOTO March 1960

Depth (meters)	Range of Speeds (knots)	Average Speed (knots)	No. of Observations	Time (hours)	Direction
10	1.00-0.0	0.49	88	115.8	NE
25	0.60-0.0	0.41	88	115.8	NE
50	0.60-0.0	0.35	87	115.8	NE
75	0.60-0.0	0.39	87	115.8	NE
100	0.80-0.0	0.42	87	115.8	NE
150	0.70-0.0	0.43	87	115.8	NNE-SE
200	0.60-0.0	0.34	87	115.8	NNE-SE

Theory dictates that, under certain ideal conditions, wind-driven surface currents should move 45° to the right of the wind.[16] Since TOTO lies in the trade wind region, which is characterized by winds from an easterly direction, the data on the water currents obtained with Roberts current meters could be used in a wind-drift current study.

The measurements of the currents taken at a depth of 10 meters along with surface wind observations were used. The angle of the current relative to the angle of the wind was computed for each observation.[17] Table 11 is a tabulation of these values.

As illustrated in table 11, there is a large scatter of the angle of deviation of the wind. More than half of the observations show that the current does not run against the wind. Moreover, the data indicate that currents to the right of the wind are more frequent than currents to the left of the wind. During the first 24 hours of observation the wind speed decreased from 15 to 0.04 knots, and the angle of the current relative to the wind decreased from 143°R to 030°R. A more ideal approach to the problem of wind-drift current would be to study individual observations made during periods of steady winds either weak or strong.

Although these data do not conclusively show a wind-driven current, they do indicate it. Therefore, irregular currents due to changing wind conditions can be expected to affect the water current structure in TOTO.

Table 11. Wind versus Current - Area R-1, TOTO - March 1960

Day	Time (Local EST)	Wind		Current		Angle of Current Relative to Wind (degrees)
		Direction (degrees)	Speed (knots)	Direction (degrees)	Speed (knots)	
9	0940	250	15	033	0.7	143R
9	1029	250	14	058	0.6	168R
9	1143	250	15	066	0.6	176R
9	1237	250	12	058	0.6	168R
9	1337	280	13	053	0.6	133R
9	1447	280	11	056	0.6	136R
9	1545	290	14	059	0.6	129R
9	1702	300	10	360	0.6	060R
9	1802	300	10	015	0.6	075R
9	1900	290	11	360	0.6	070R
9	2015	320	12	029	0.4	069R
9	2125	300	12	026	0.2	086R
9	2310	320	10	-	0.2	-
10	0115	320	10	022	0.3	062R
10	0218	320	09	022	0.3	062R
10	0320	320	10	035	0.5	075R
10	0427	320	10	044	0.4	088R
10	0537	320	10	046	0.2	086R
10	0645	320	08	055	0.2	095R
10	0800	330	08	360	0.2	030R
10	0930	330	04	360	0.4	030R
10	1030	340	04	306	0.3	034L
10	1138	340	07	313	0.3	027L
10	1300	350	03	025	0.4	035R
10	1405	350	05	022	0.5	032R
10	1515	360	06	000	0.5	0
10	1645	360	07	020	0.5	020R
10	1746	360	07	026	0.5	026R
10	1840	230	04	025	0.5	155R
10	1937	230	04	023	0.5	153R
10	2035	180	09	021	0.5	159L
10	2140	180	09	000	0.5	180L R
10	2245	180	10	022	0.45	158L
10	2350	180	10	028	0.5	152L

Table 11. Wind versus Current - Area R-1, TOTO - March 1960 (cont'd)

Day	Time (Local EST)	Wind Direction (degrees)	Wind Speed (knots)	Current Direction (degrees)	Current Speed (knots)	Angle of Current Relative to Wind (degrees)
11	0100	180	08	032	0.4	148L
11	0204	180	08	338	0.4	158L
11	0305	180	06	054	0.5	126L
11	0410	200	07	027	0.6	173L
11	0512	200	06	040	0.4	160L
11	0620	270	07	035	0.5	125R
11	0745	310	07	047	0.6	097R
11	0839	310	07	051	0.6	101R
11	0940	320	08	035	0.5	075R
11	1040	340	10	035	0.5	055R
11	1133	000	10	038	0.5	038R
11	1224	000	11	045	0.5	045R
11	1317	000	11	079	0.5	079R
11	1404	320	11	065	0.6	105R
11	1448	320	11	048	0.6	088R
11	1536	320	13	061	0.8	101R
11	1708	320	11	062	0.8	102R
11	1802	330	11	070	0.8	100R
11	1900	340	09	040	0.3	060R
11	1950	340	09	-	<0.2	-
11	2049	340	08	015	0.4	035R
11	2145	000	05	340	0.2	020R
11	2300	000	07	250	0.3	110L
12	0014	000	07	170	0.4	170L
12	0110	070	09	158	0.4	088R
12	0210	070	12	132	0.3	062R
12	0314	050	13	118	0.35	068R
12	0424	050	13	094	0.3	044R
12	0520	080	14	083	0.3	003R
12	0618	070	12	086	0.3	016R
12	0705	060	11	115	0.6	055R
12	0810	080	10	113	0.6	033R
12	0903	080	11	127	0.6	047R
12	0957	070	11	129	0.7	059R
12	1050	060	10	123	0.8	063R
12	1155	060	10	143	0.7	083R
12	1320	150	19	126	1.0	024L
12	1410	160	22	122	1.0	038L

Table 11. Wind versus Current - Area R-1, TOTO - March 1960 (cont'd)

Day	Time (Local EST)	Wind		Current		Angle of Current Relative to Wind (degrees)
		Direction (degrees)	Speed (knots)	Direction (degrees)	Speed (knots)	
13	1530	200	03	192	0.5	008L
13	1620	250	10	125	0.4	125L
13	1710	280	14	137	0.5	143L
13	1809	280	14	130	0.4	150L
13	1903	260	11	120	0.6	140L
13	1955	260	11	155	0.5	105L
13	2045	260	11	133	0.5	127L
13	2135	260	10	129	0.6	131L
13	2223	260	12	129	0.6	131L
14	0010	250	11	128	0.5	122L
14	0103	270	11	133	0.5	137L
14	0148	270	11	124	0.5	146L
14	0235	270	12	120	0.6	150L
14	0400	150	12	133	0.6	017L
14	0458	150	12	145	0.6	005L
14	0553	150	13	115	0.6	035L

NJOS[18] used Roberts current meters to make another series of water current measurements in TOTO during the period 28 January to 9 February 1962. A ship was anchored in a three-point moor in area R2 (see figure 1). Although measurements were made at various depths from 2 to 1500 meters, the bulk of the data were collected at depths of 10, 15, 50, 100, and 150 meters. Some of the measurements were made consecutively at various depths. The averages and ranges of the current speeds are presented in table 12, and all the data obtained are tabulated in Appendix C, table C-2.

Table 12. Average Speed and Direction of Currents - Area R2 TOTO February 1962

Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	No. of Observations	Time (hours)	Direction (degrees)
10	18.0 - 5.0	12.5	32	17.2	195 - 240
15	23.5 - 5.0	11.0	30	20.8	140 - 320 (Var)
50	17.5 - 5.0	12.5	43	15.0	020 - 160
100	16.5 - 5.0	10.0	37	23.1	Variable
150	17.5 - 5.0	11.0	49	24.8	Variable

Although data shown in table 12 were taken over a four-day period, it appears that the currents in the upper 150 meters of the water column were quite uniform with respect to average speeds but lacked uniformity with respect to direction. The maximum and minimum current speeds also indicate a uniformity in the vertical current structure.

It should be noted that the average current speeds observed in area R2 during January-February 1962 were about one-half the magnitude of the average current speeds observed in area R1 during March 1960.

Individual measurements were also made at 800, 1000, 1200, 1500 meter depths. In all cases the direction of the current was S and the current speeds were 5.0 cm/sec.

Since a majority of the observations were taken over a time interval exceeding the tidal cycle, a study was made to determine if the tidal current could be resolved from the data.

The directions and magnitudes of the currents observed at a depth of 10 meters were averaged individually. The average current was then vectorally subtracted from the individual observations. The resultant current vectors were plotted on a time axis. Figure 18 is a diagram of the resultant vectors versus time. The diagram shows a definite reversal in the current with apparent maximums in both cases. Between the reversal of the current there is an indication of a nodal point, and the period of the tidal current is very nearly that of the tides which had been measured in the area though not concurrent with the actual current observations.*

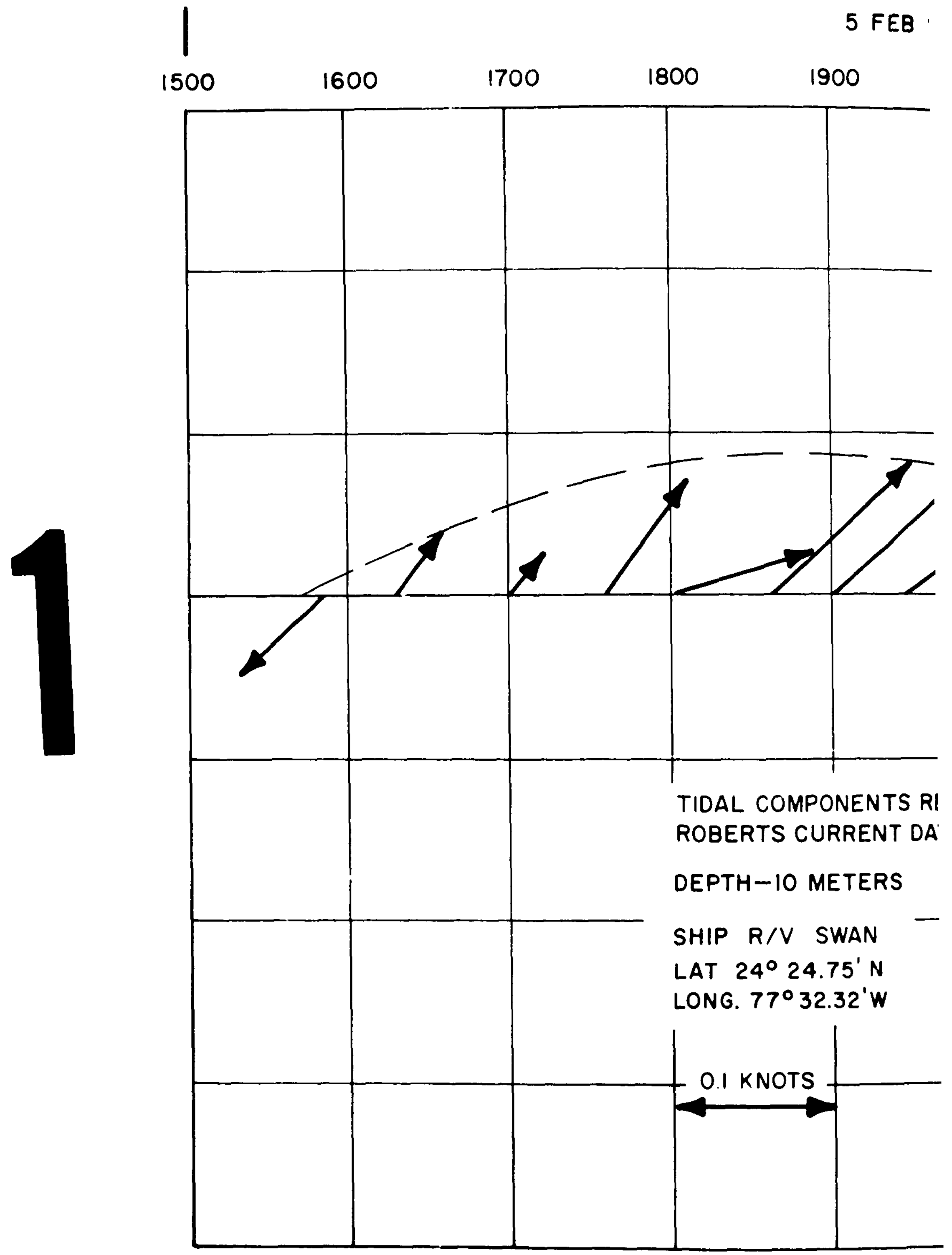
The same method was applied to the serial observations taken at depths of 50 and 150 meters. These are shown in figures 19 and 20. Although they do not exhibit a period as close to the actual tidal period as did the observations at the 10 meter depth,they nevertheless indicate a tidal influence in the form of a periodic reversal in current direction with a corresponding decrease and increase in magnitude.

Tilt Device

General Motors Corporation took a series of measurements with a tilt device[5] that was built into an experimental array designed primarily to track underwater vehicles in three dimensions. These measurements were made at the bottom of TOTO in area E2 (see figure 1), and the data have been processed to indicate the speed and direction of water currents. The observations were made during the period 1 to 8 February 1962.

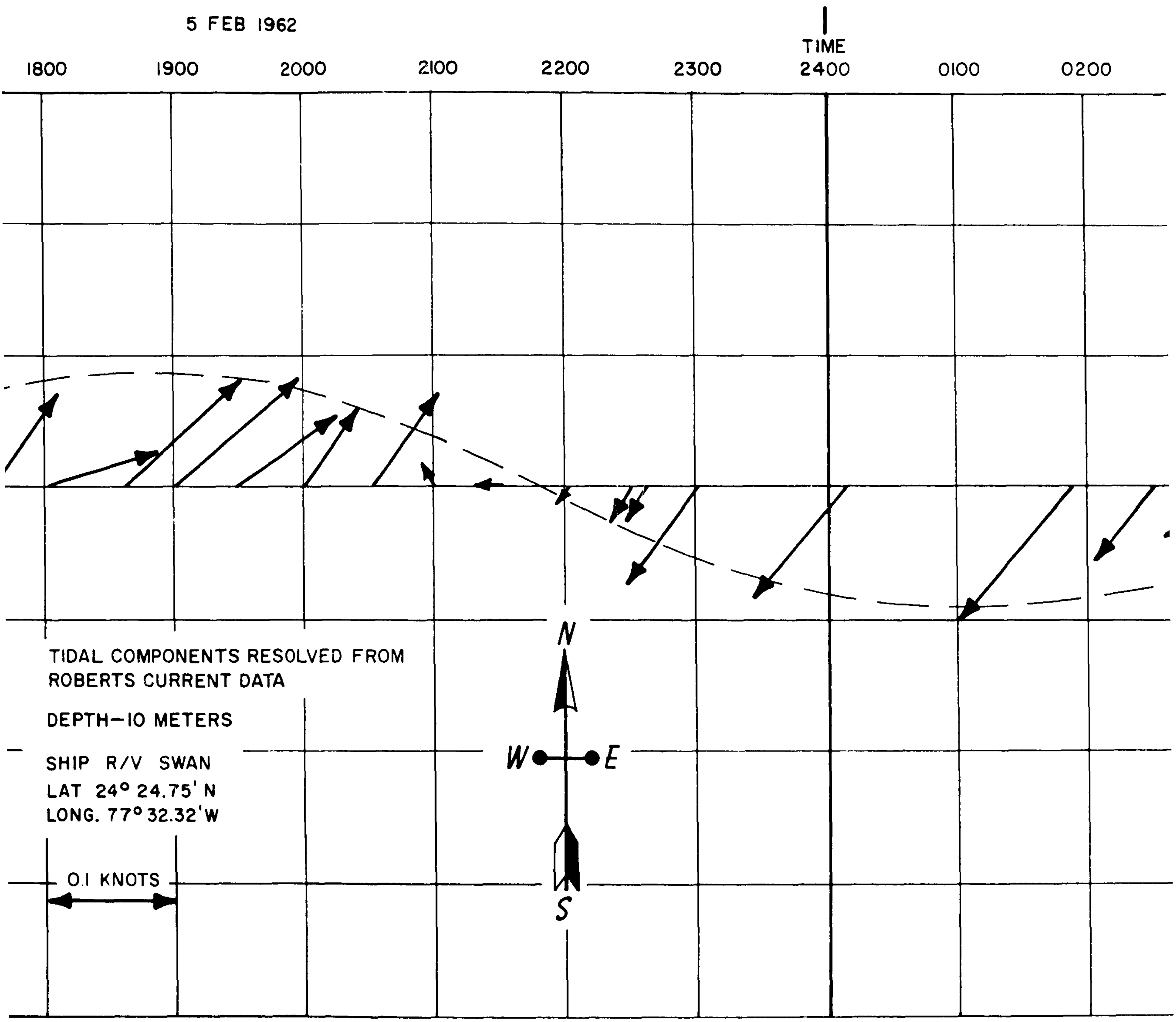
Figure 21 is a graphic display of the water current measurements taken on the bottom of TOTO. The upper curve represents the calculated current speed versus time, and the lower curve represents the change in current direction versus time. A tabulation of the data is presented in Appendix D, table D-1.

*(See tidal data from Nassau, table 7.)



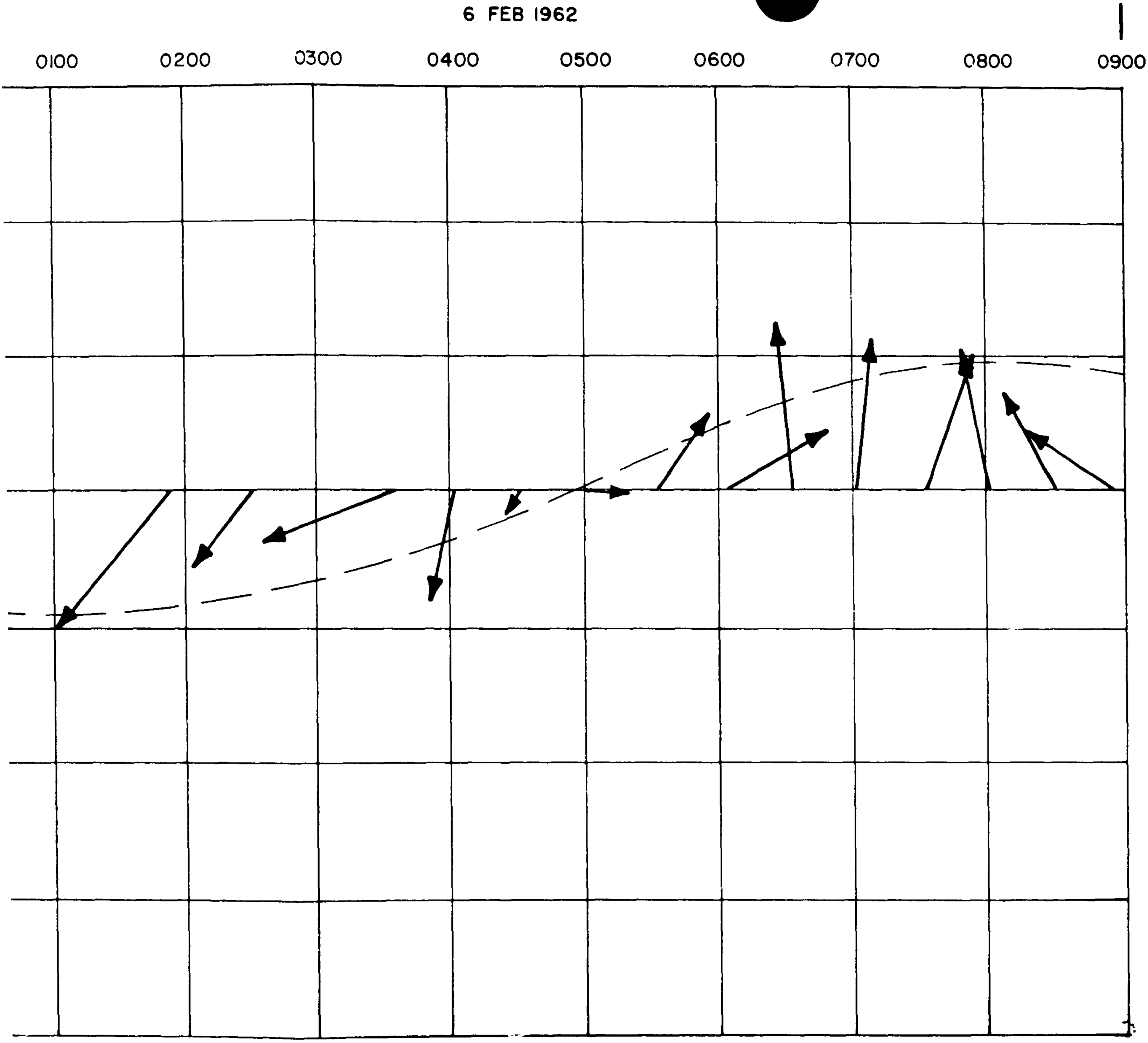
1
5 FEB
1500
1600
1700
1800
1900
TIDAL COMPONENTS R
ROBERTS CURRENT DA
DEPTH—10 METERS
SHIP R/V SWAN
LAT 24° 24.75' N
LONG. 77° 32.32' W
0.1 KNOTS

FIGURE 18

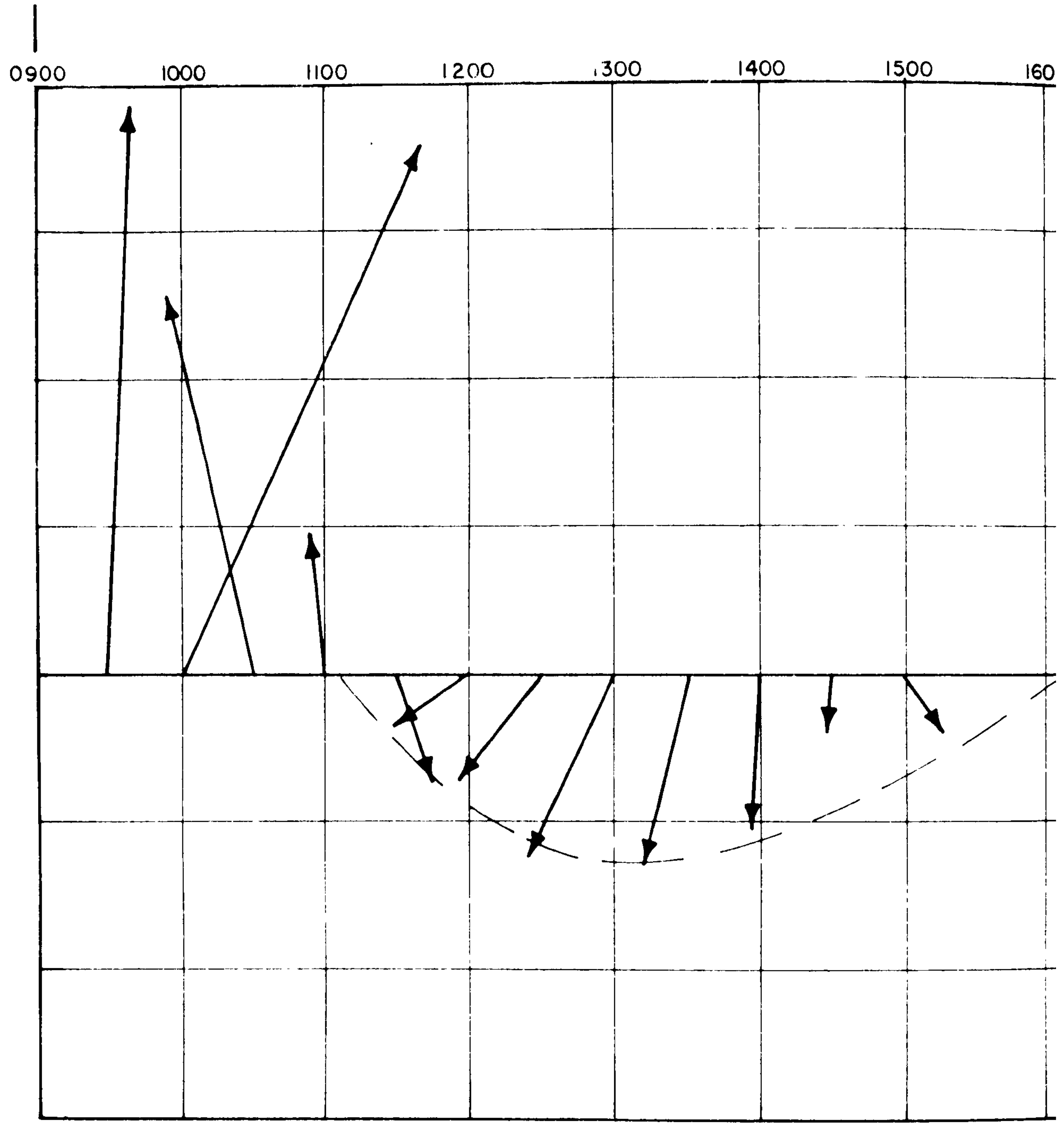


Tidal Components Resolved from Continuous Current Measurements – 5 & 6 Februa

3



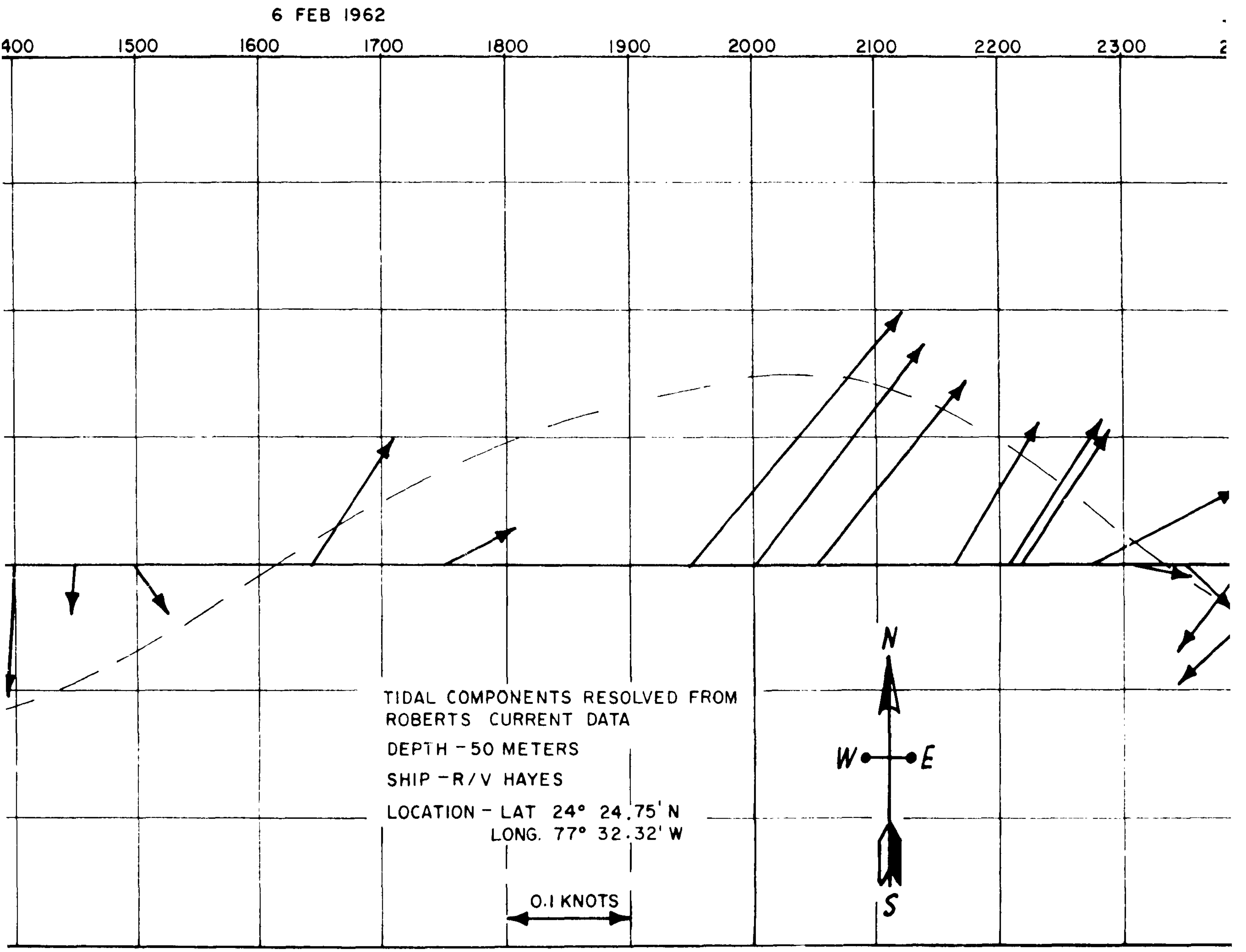
Measurements - 5 & 6 February 1962



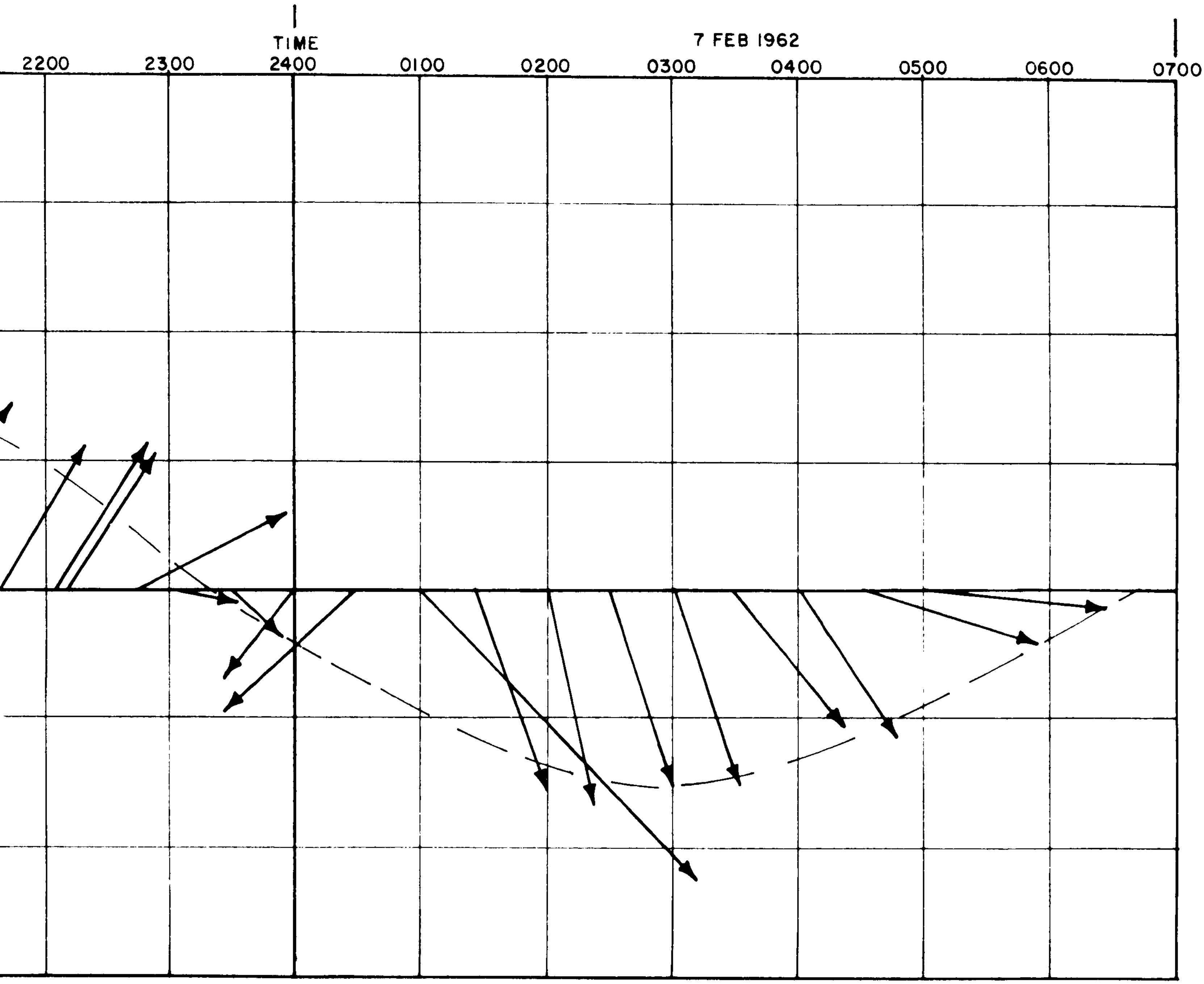
1

FIGURE 19

2



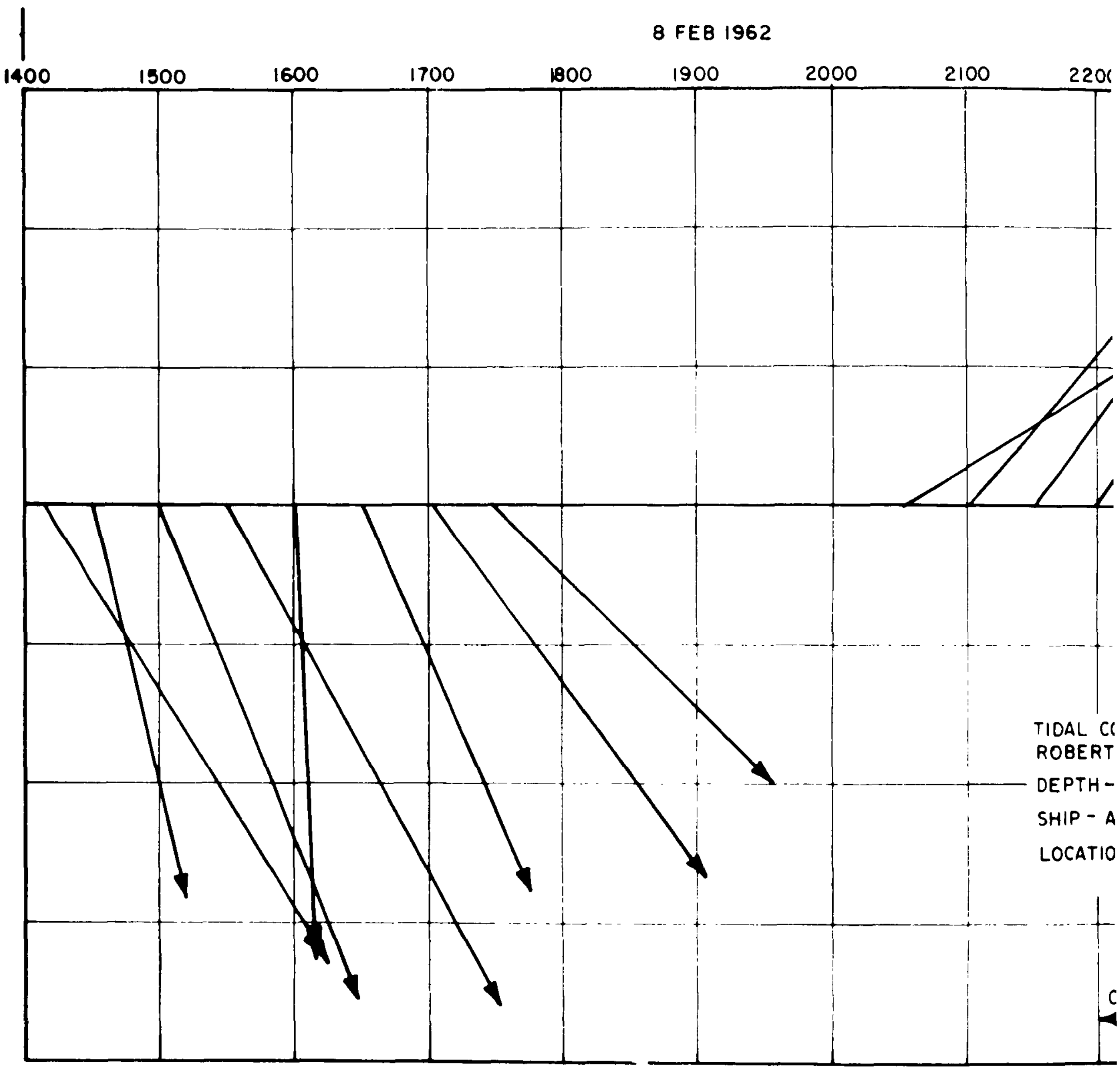
Tidal Components Resolved from Continuous Current Measurements - 6 & 7 February 1962



ts - 6 & 7 February 1962

3

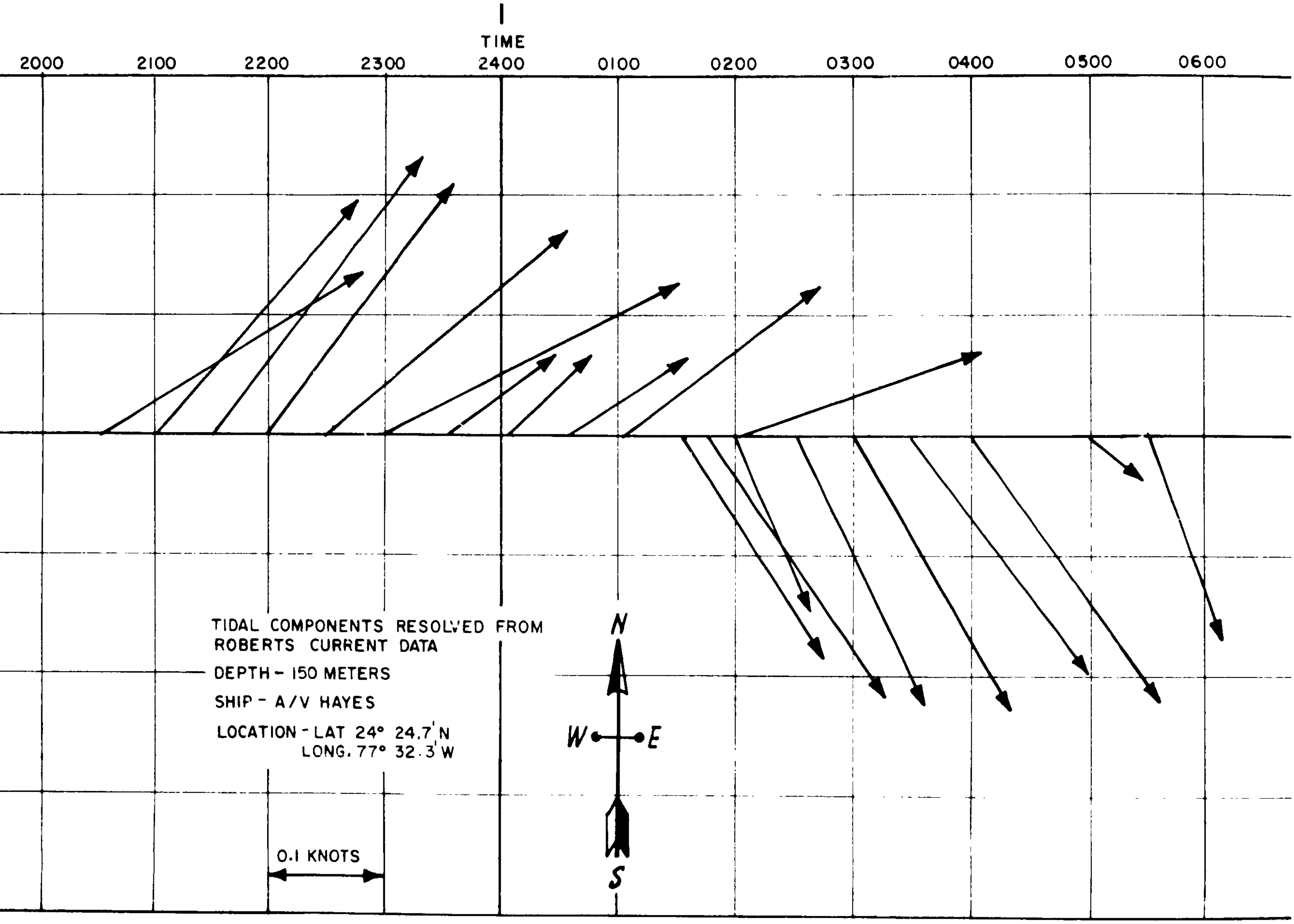
1



8 FEB 1962
1400
1500
1600
1700
1800
1900
2000
2100
2200
TIDAL C
ROBERT
DEPTH -
SHIP - A
LOCATIO

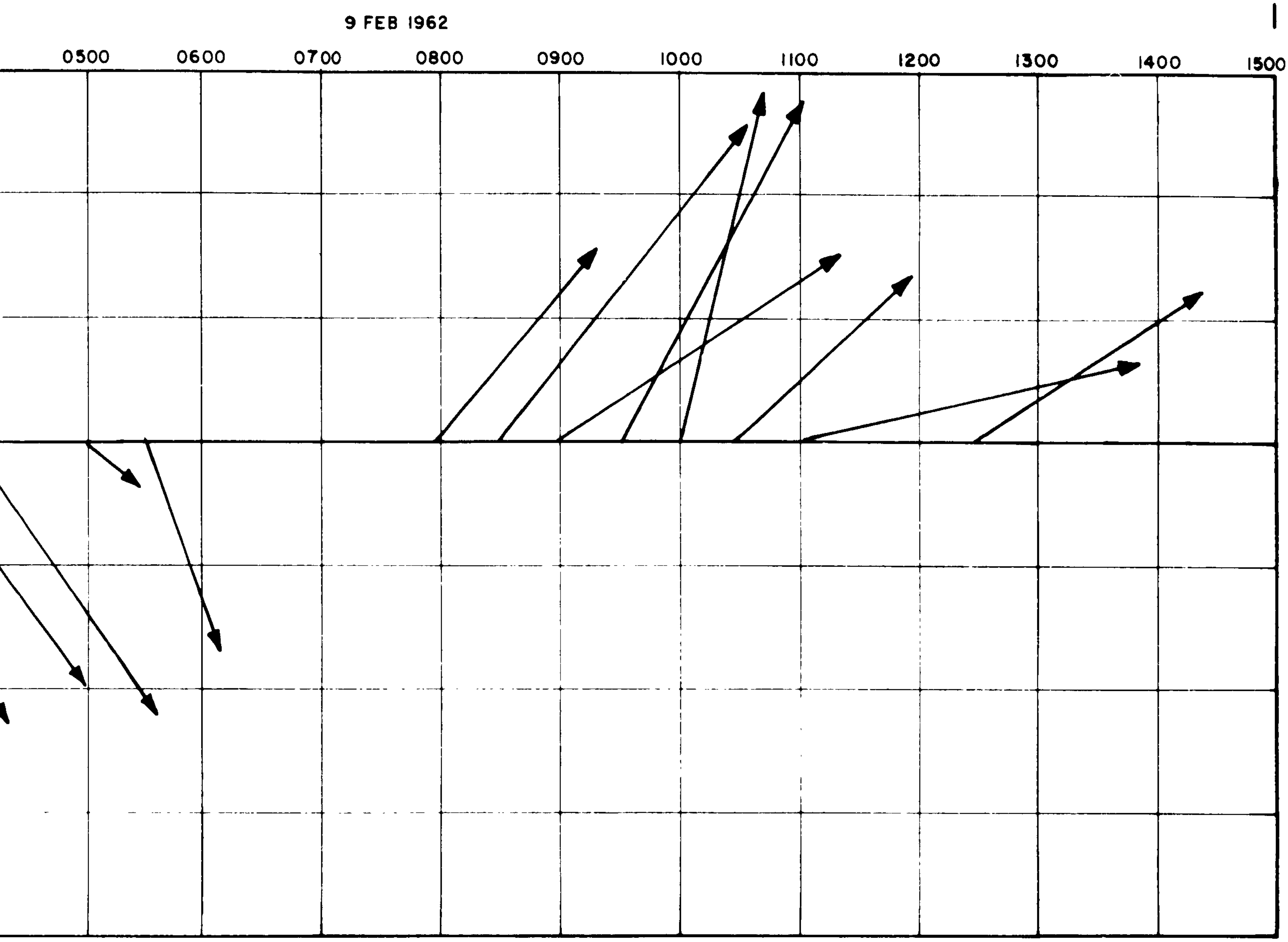
FIGURE 20

2



Tidal Components Resolved from Continuous Current Measurements - 8 & 9 February 1962

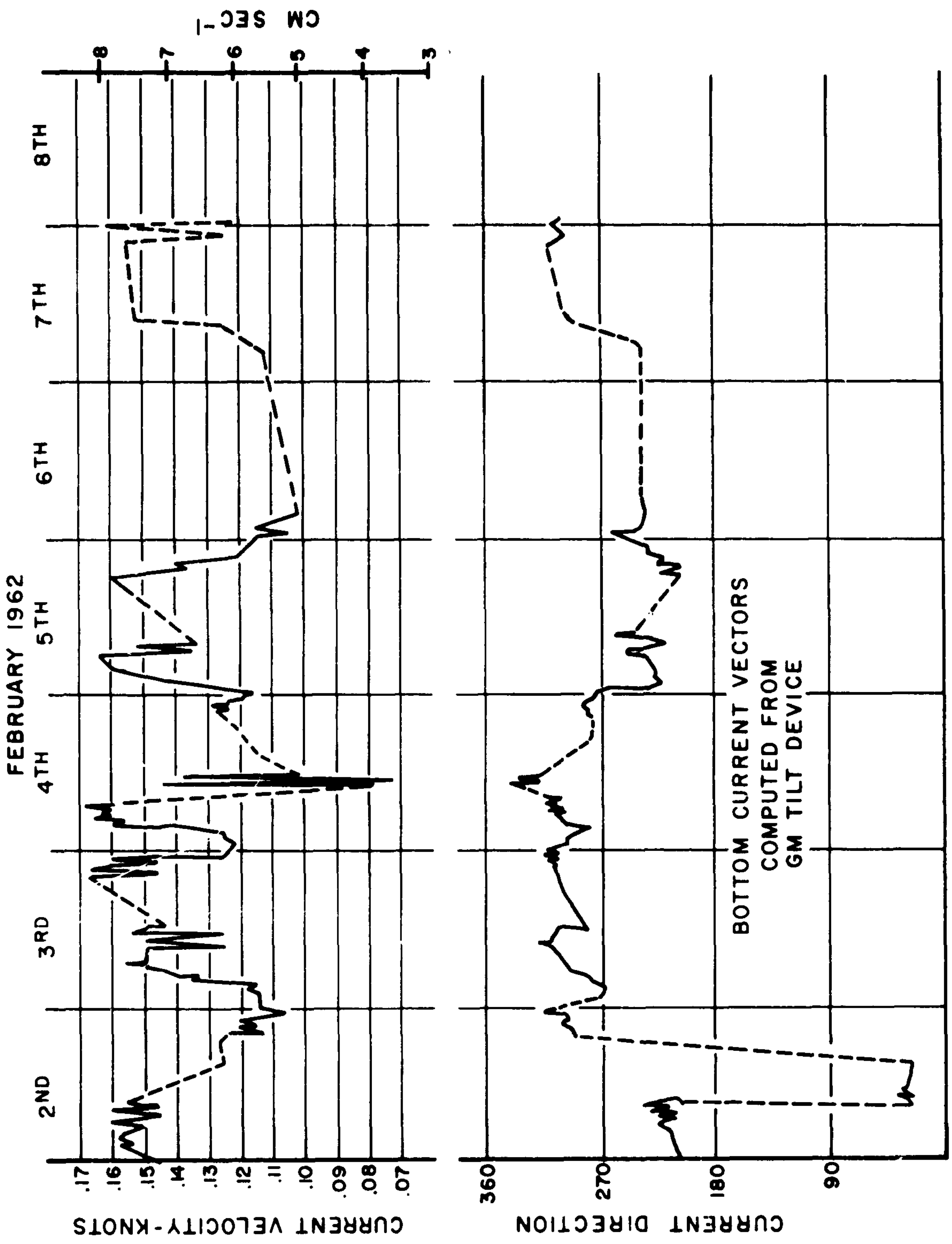
3



nts - 8 & 9 February 1962

Short period (1-2 hours) fluctuations in the current speed are quite apparent and seem to be superimposed on longer period fluctuations (6-12 hours). From the upper curve, figure 21, tidal movement seems to be indicated in the form of small fluctuations (1 cm/sec) in the current speed, occurring at intervals of time corresponding somewhat to that of a semidiurnal tide. The periods of "high" current speed and "low" current speed during the third and fourth days of these observations also appear to be tidal in nature. However, the data available on both the tides and currents in this area are insufficient to substantiate this hypothesis. The maximum current speed was 8.9 cm/sec toward the NW, and the minimum current speed was 3.6 cm/sec toward the NNW. The average speed of the currents was 6.9 cm/sec, and the range was about 5 cm/sec.

A greater range may exist, but an explanation of this would depend on a better understanding of the origin of the bottom currents. It is possible that the Antilles current can affect the bottom currents in TOTO, giving rise to greater current speeds and/or large, short-period fluctuations in current speeds.



Current Velocity vs Time - TOTO Tilt Area - 2 to 8 February 1962

FIGURE 21

ANALYSIS OF THE DATA

In analyzing the water current data obtained with drogues in TOTO, it seems that at least one drogue in each series did not conform to the general motion of the others, or to that which might be expected from previous measurements. The quality and/or reliability of these data might have been affected by the following:

1. Lack of good navigation information. Inaccuracies in some of the methods used to obtain fixes on the surface floats (visual or radar) could account for some discrepancies.

2. Insufficient observation time (less than one tidal period). To be able to determine the effects of tidal movements, drogues must be tracked for at least one tidal period and perferably longer.

3. Inherent weaknesses in the drogue design. It is possible that interfaces or sheer zones were present which affected the drogue at the depth being measured, or that the current was less than the device could adequately measure.

4. Variations in drogue designs. Since the design of floats, types of drags, etc. varied, the quality or reliability of the data may have varied.

The drogue measurements made in areas D11, D12, and D13 (see figure 1) by WHOI are considered to be the most complete with respect to synoptic and systematic coverage over a relatively short time interval (10 days).

Water current measurements made with Ekman current meters have provided the best data on tidal currents in TOTO both on and off the banks. However, the area coverage is spotty, and tide station data are not available for the same time periods for comparison. Although the Ekman current meter probably yields the best current measurements in terms of the accuracy of the meter itself, it has one inherent weakness. The meter must be raised and the data read before additional measurements can be taken. This is a drawback when continuous measurements of deep currents are desired.

Water current measurements made with Roberts current meters are the largest source of nearly continuous current data in the upper 200 meters of TOTO. Although the data are narrow in scope, and are not fully analyzed in this report, it appears that additional knowledge of the surface layer could be gained from a more extensive analysis. Such an analysis might consist of a statistical study of variations in current velocity with depth, variations in current velocity with time at a given depth, etc.

The data collected on the water currents in TOTO are narrow in scope, spotty, and very limited in application. Consequently, the analysis of the data presented in this report is intended to give only a generalized picture of the current structure in TOTO which may be of importance to the installation and maintenance of underwater tracking systems, and should be used with reservations unless otherwise specified.

Surface Currents

Water currents in the surface layer of TOTO (0 to 200 meters) measured with drogues, Ekman and Roberts current meters varied greatly in speed and direction. This variability may be attibuted to a number of factors which may act simultaneously or independently of each other, namely: the eastern trade winds and other meteorological influences, tidal effects, effects due to water movement outside TOTO, and the close proximity of a large land mass (Andros Island). In addition, the extremely large expanse of shallow water (Bahama Banks) and the numerous islands and cays serve to affect the surface circulation in and around TOTO.

Averages of the speeds of the currents at various depths to 200 meters have been compiled from all the measurements taken, except those taken along the banks, and are presented in table 13.

Table 13. Average Speeds of Currents in the Surface Layer of TOTO

Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	No. of Observations
10	87.0 - <5	21.0	185
25	31.0 - <5	20.0	93
50	31.0 - 1	15.0	191
75	31.0 - <5	20.0	87
100	107.0 - <5	18.5	155
150	36.0 - <5	18.5	127
200	41.9 - 1	13.5	209

This partial analysis indicates that the average speed of the currents in the surface layer of TOTO generally decreases with increasing depth. No general circulation pattern can be predicted because of the limited amount of data available, the numerous factors which could have affected the reliability of the measurements, and the extreme variation in the directions of the currents measured.

Subsurface Currents (Excluding Bottom Currents)

Most of the information on the subsurface currents in TOTO (200 to 1000 meters) was obtained with drogues. However, a few measurements were taken with Ekman and Roberts current meters.

Averages of the speeds of the subsurface currents from 250 to 1000 meters are presented in table 14. The range of speeds, also presented in table 14, shows the variability that exists in the current structure throughout the water column.

Table 14. Average Speeds of Subsurface Currents in TOTO (250 to 1000 Meters)

Depth (Meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	No. of Observations
250	28.0 - 2.5	9.0	18
350	10.0 - 5.0	7.0	5
500	46.5 - 1.1	6.5	106
750	15.5 - 2.5	7.0	21
1000	31.0 - 2.5	10.5	16

This analysis indicates that the average speeds of the subsurface currents are lower than the average speeds of the currents in the surface layer. Although no general circulation pattern could be determined, an analysis of individual measurements indicates that the subsurface currents in TOTO are partly tidal in nature.

Bottom Currents

The only data available on the bottom currents in TOTO were obtained with the tilt device on the General Motors experimental model of a deep water tracking system. From these data, the average speed of the water current at a depth of 1500 meters was computed to be 6.9 cm/sec, with a range of speeds from 8.4 to 3.6 cm/sec.

A plot of the data (current velocity vs time, figure 21) shows numerous fluctuations in the speed of the current. It is noted, however, that two maximum and two minimum speeds occurred each day (where observations were numerous), indicating a periodic fluctuation comparable to that of the semidiurnal tide.

Although one observer, using the photographic technique,[20] inferred greater bottom currents in one or two areas of TOTO, the large number of bottom photographs obtained by Athearn and Ziegler[21] do not confirm this.

Since the data available on the bottom currents in TOTO are so limited, much more information will be required before a synoptic picture of the current structure or a general circulation pattern can be determined.

Vertical Current Gradients

Knowledge of the magnitude of water currents can be important to the installation and maintenance of various types of moors or instrumented arrays in deep water, since a drag effect, proportional to the square of the speed of the current, will be exerted on the moor or array.

The data obtained on the water currents in TOTO were analyzed to indicate the vertical current gradients, and curves were drawn (figure 22) to represent the range of current speeds and the average current speeds at various depths. It should be noted that average speeds of the currents (disregarding directions) were used in plotting these curves as opposed to a vectorial average of current velocities. (Using a vectorial average might have removed the tidal component of the current which could have contributed a large portion of the drag.)

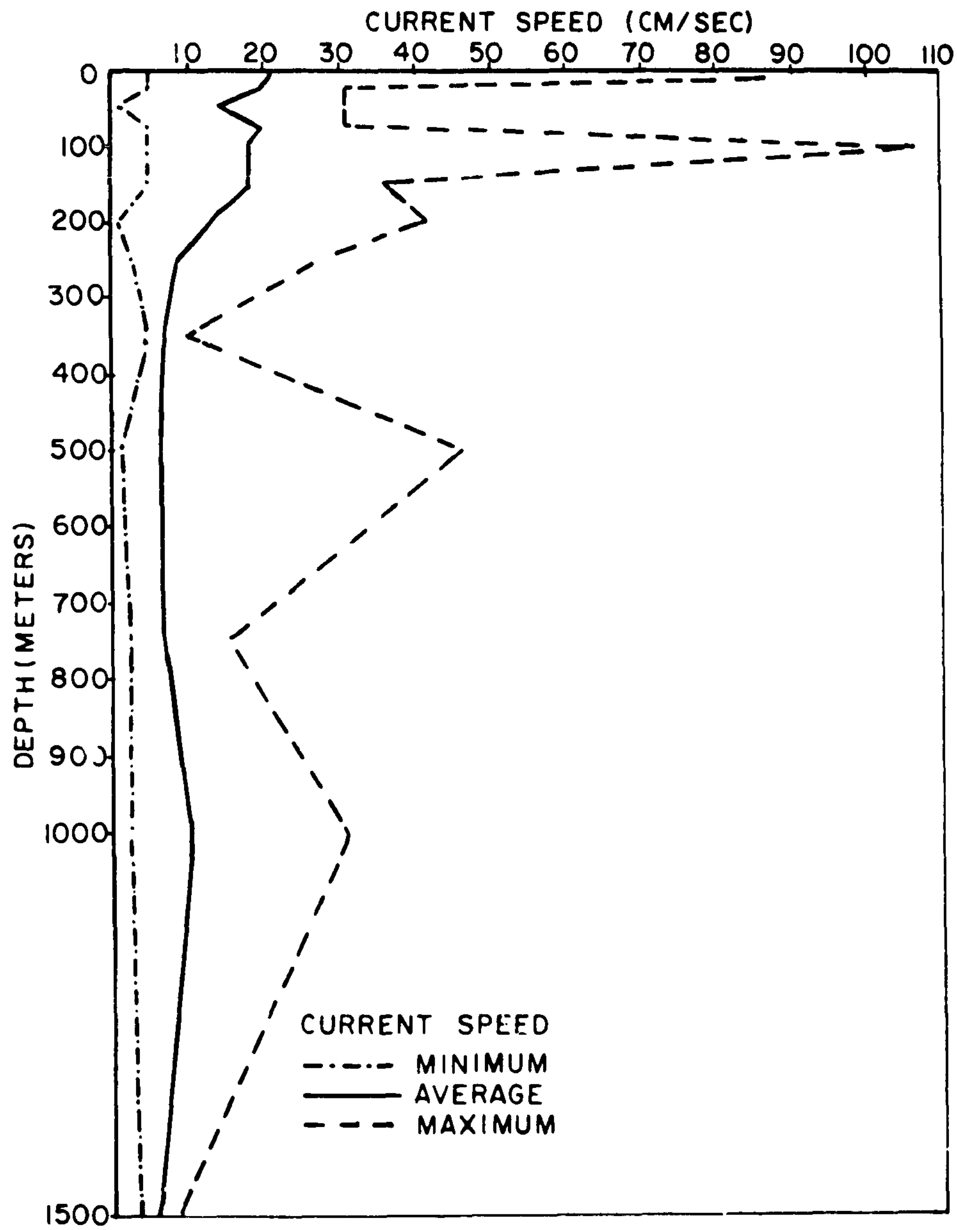
This analysis shows that the average speed of the currents in TOTO is greatest in the upper 150 meters of the water column. The speed decreases almost linearly between 150 and 250 meters, with a gradient of 9.5 cm/sec in 100 meters. At depths below 250 meters the speed of the currents is generally less than 10 cm/sec.

Since the range of current speeds is also greatest in the upper 150 meters of the water column, the drag exerted by the current will be much more severe in this surface layer than at deeper depths. Moors or arrays that extend into the surface layer of TOTO may be subjected to currents with speeds up to 90-100 cm/sec ($\sim$ 2.0 knots), and this could increase during periods of extreme weather.

Turbulence

Laminar flow, in which layers of water move in an orderly manner, is not known to occur in the ocean. Ocean currents are characterized by numerous eddies of varing dimensions by which small masses of water are carried into regions of a different velocity.[16] This irregular type of motion is called turbulent flow, and the process by which a rapid exchange of water masses is maintained is called turbulence.

While inaccuracies in tracking might account for the action in some cases, many of the drogue measurements discussed showed rapid fluctuations of velocity, and the tracks were erratic indicating a non-steady motion. Since rapid fluctuations of velocity and non-steady motion of individual particles are characteristic of turbulent flow, the water current structure of TOTO appears to be turbulent in nature at all depths where drogue measurements were taken.



Current Speed vs Depth - All Areas of TOTO

FIGURE 22

The idea of a turbulent system existing in TOTO offers some interesting speculations as to the driving force of such a system:

1. Since TOTO can be compared to a bathtub open (to the ocean) at one end, the intrusion of turbulent eddies is certainly possible.

2. Eddies might enter through the NE Providence Channel and migrate through TOTO.

3. The size, velocity, and duration of such eddies would be limited by the configuration of TOTO.

If, as seems probable from the existing data, turbulent eddies are present, more information about the nature of the general flow of water outside TOTO and on the surrounding banks will be required to determine how the turbulent areas are created and related to the flow. It is also important to know the magnitude and scale length of these turbulent eddies before attempting to measure or predict other parameters (magnitude of currents in small areas, general circulation, etc.) by placing moored current meters in the deep water of TOTO.

General Circulation

In the literature from which the data for this report were extracted, two modes of general circulation have been hypothesized:

1. Clockwise Circulation. A pattern of circulation in which the water in TOTO courses southward in the eastern portion, gradually curving westerly, and then setting northerly through the western portion.

2. Counterclockwise Circulation. A pattern of circulation directly opposite to that shown in (1).

From the drogue tracks presented in Appendix A (figures A-23 through A-32), a third mode of circulation is suggested; that is, the currents in the upper 200 meters of the water column course northward while the currents at 500 meters course southward. This is the most unlikely mode of general circulation in TOTO because shear zones would have to be maintained from outside TOTO.

A majority of the data obtained on the water currents in TOTO are narrow in scope, taken at random and not synoptic enough to analyze with respect to predicting the general circulation pattern. In addition, the general circulation pattern may be obscured by what appears to be a turbulent system of transport.

CONCLUSIONS

Although inaccuracies in tracking, due to the navigation methods used in tracking many of the drogues, could have affected the quality of these measurements, a partial analysis of all the data collected on the water currents in TOTO indicates:

1. The current structure (particularly at the surface) is to a large degree of a turbulent nature; i.e., there is a lack of a clearly defined mean motion such as one detects in the regime of the Gulf Stream.

2. The surface motion tends to be affected by the boundary tidal effects, but just how far out from the banks this effect reaches is not known.

3. The deep water motion (greater than 300 meters) must acquire its energy and momentum from the NE and/or NW Providence Channels, since the surface water (bank water) cannot penetrate below about 300 meters.

4. No general circulation pattern, either in the surface waters or at depth, has been clearly defined. This does not mean none exists. A mean flow of deep water in and out TOTO must exist, but the rate of flushing is not known.

5. The speeds of the water currents generally decrease with increasing depth.

Since the distribution of the existing data is sporadic in both time and space, a more systematic and synoptic coverage of the water currents in TOTO is needed to:

1. Determine the general circulation pattern(s).

2. Determine the general magnitude and intensity of horizontal and vertical current shear.

3. Determine the extent and time scale required for mixing and the transport of bank water into the AUTEC area.

4. Determine the mixing length of the predominant eddies in TOTO.

5. Determine if the motions in the deep water can be traced to motions occurring at the entrance to the NE Providence Channel.

6. Determine the relation between the wind drift patterns of the water currents and the tidal movements.

RECOMMENDATIONS

Before a reasonable attempt can be made to solve such specific problems associated with the water current structure as local advection, vertical velocity shear, horizontal mixing, maximum and minimum current velocities expected, etc., and the effects of these phenomena on tests and evaluations conducted with the underwater tracking systems, the general circulation pattern(s) must be determined.

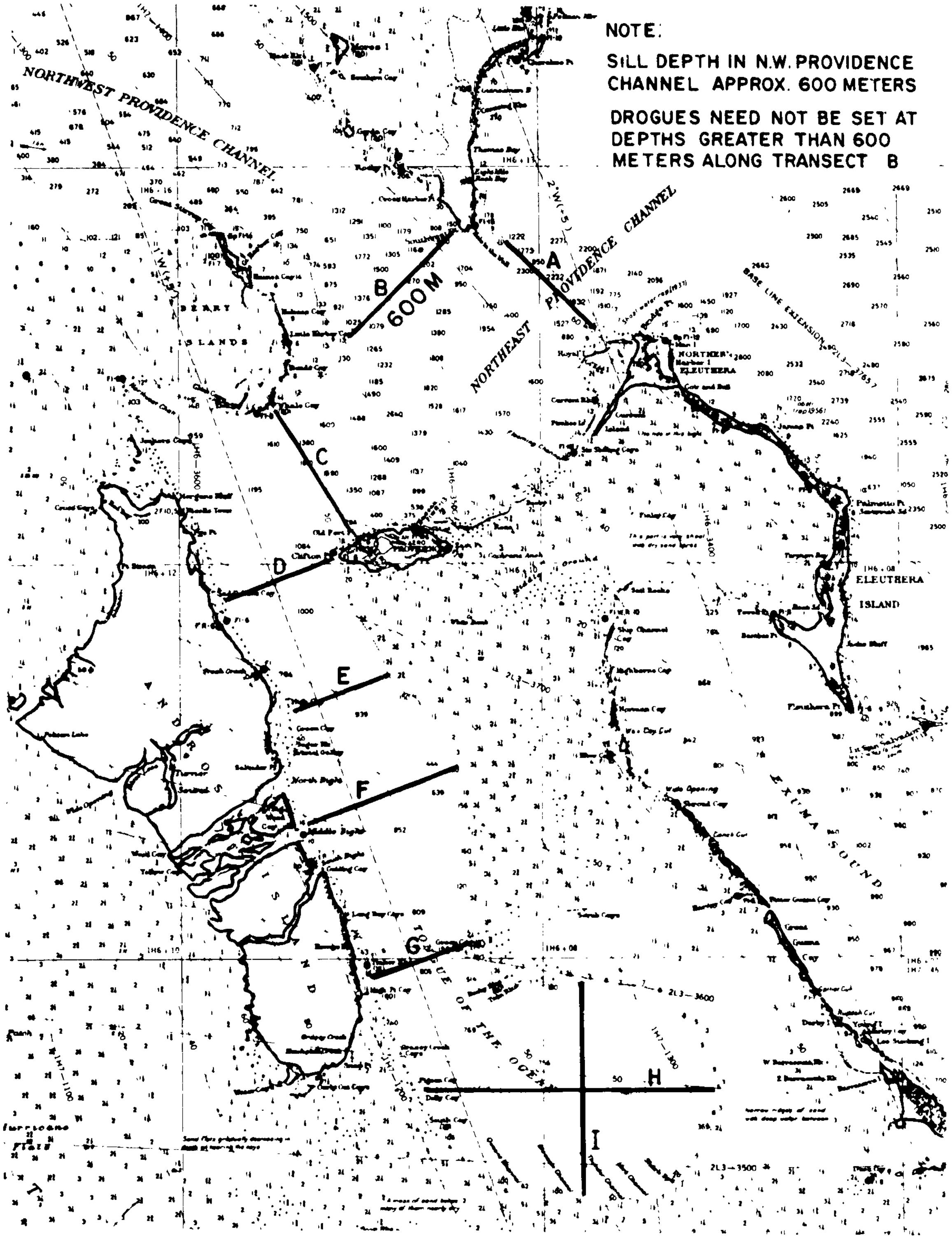
It is recommended that an intensive,well-planned program of measuring water currents be initiated to determine the general flow pattern(s) in TOTO. It is further recommended that the initial phase of this program consist of the following:

1. A large number of drogue measurements taken along various transects from the NE Providence Channel to the southern extremity of TOTO (Cul de Sac). Recommended transects are shown in figure 23.

2. Measurements should be taken at depths where the measured motion is representative of the motion in the water column. Oceanographic station and water current data can be used as an aid in selecting the depths.

3. Each drogue should be tracked for a minimum of three days.

4. Two or more drogues should be tracked simultaneously over different transects, and at least two small, fast research vessels will be required.



Areas Recommended for Additional Drogue Water Current Measurements

FIGURE 23

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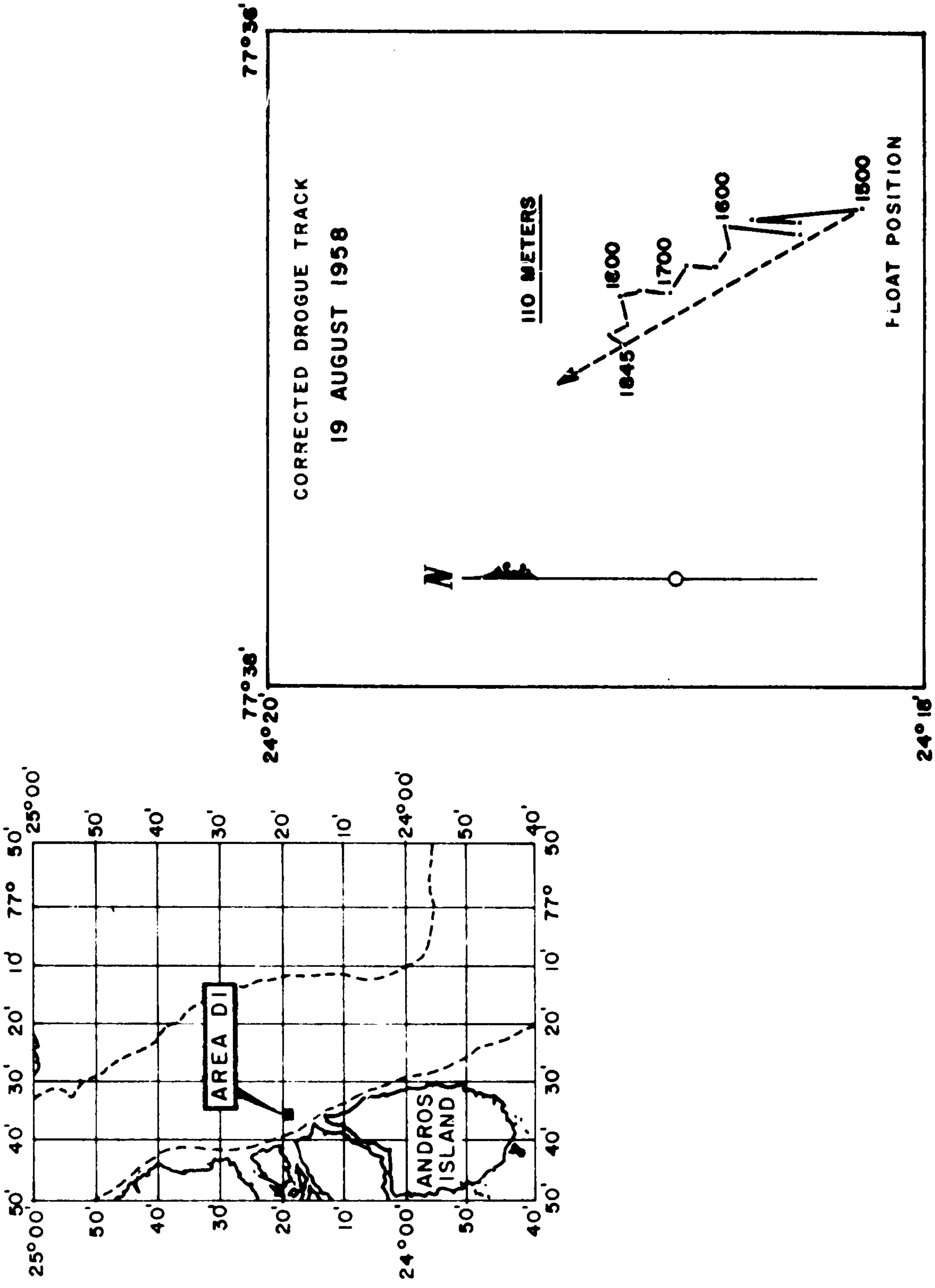
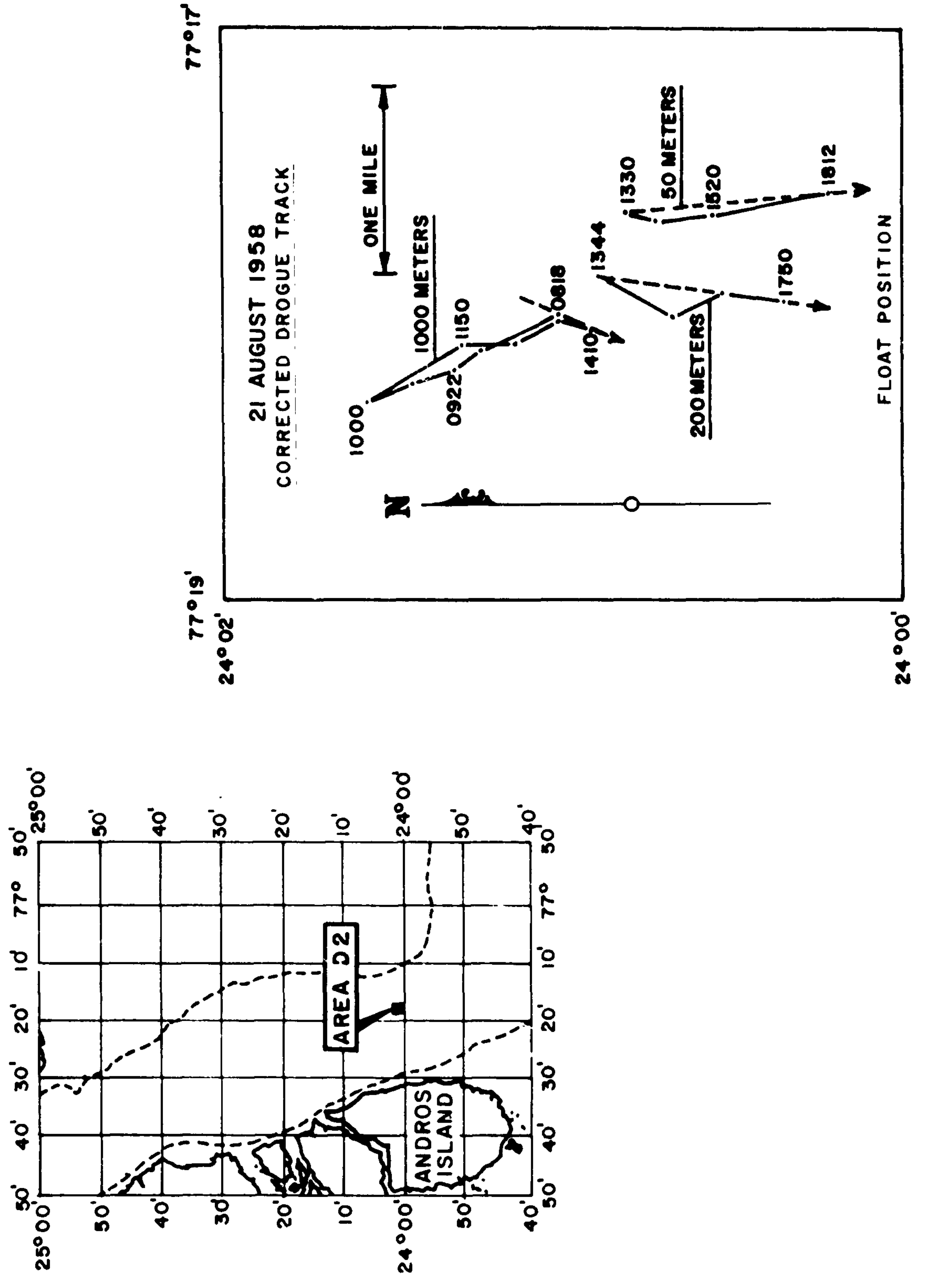
APPENDIX A

A summary of the data and drogue tracks for water current measurements taken in TOTO.



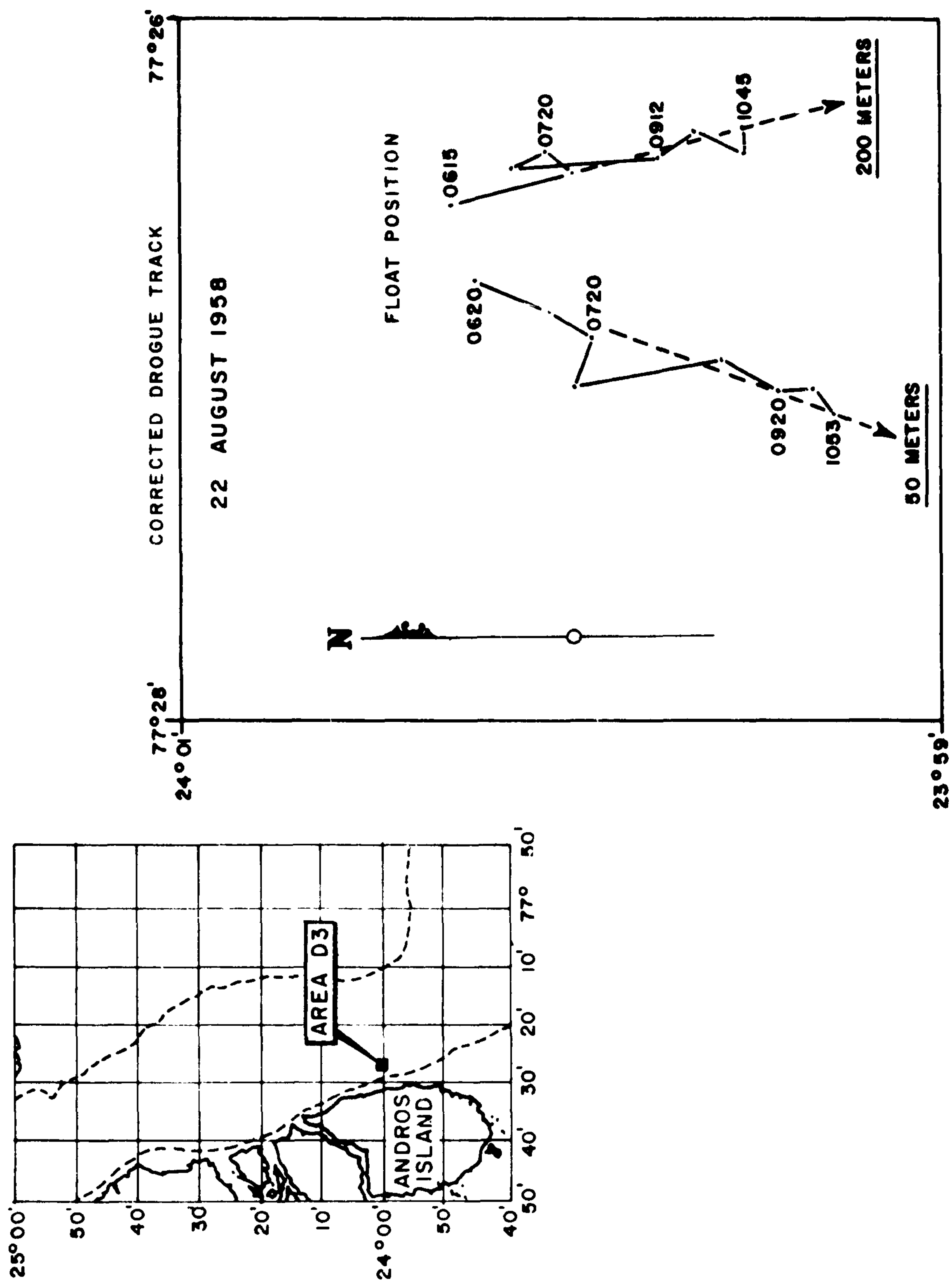
Drogue Current Observations - Area D1 - Depth 110 Meters

FIGURE A-1



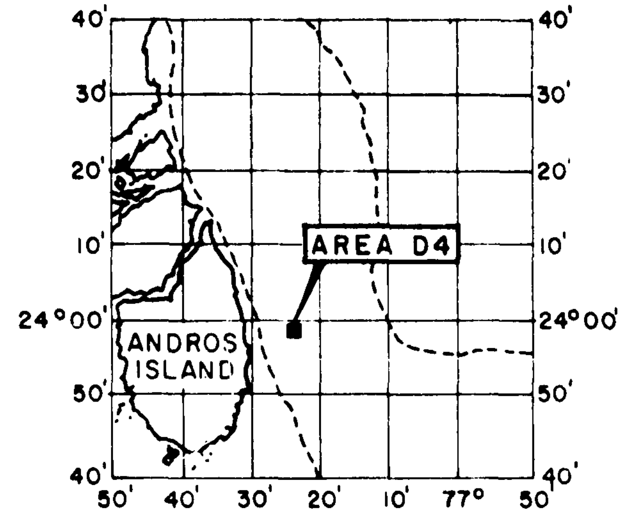
Drogue Current Observations - Area D2 - Depths 50, 200, and 1000 Meters

FIGURE A-2

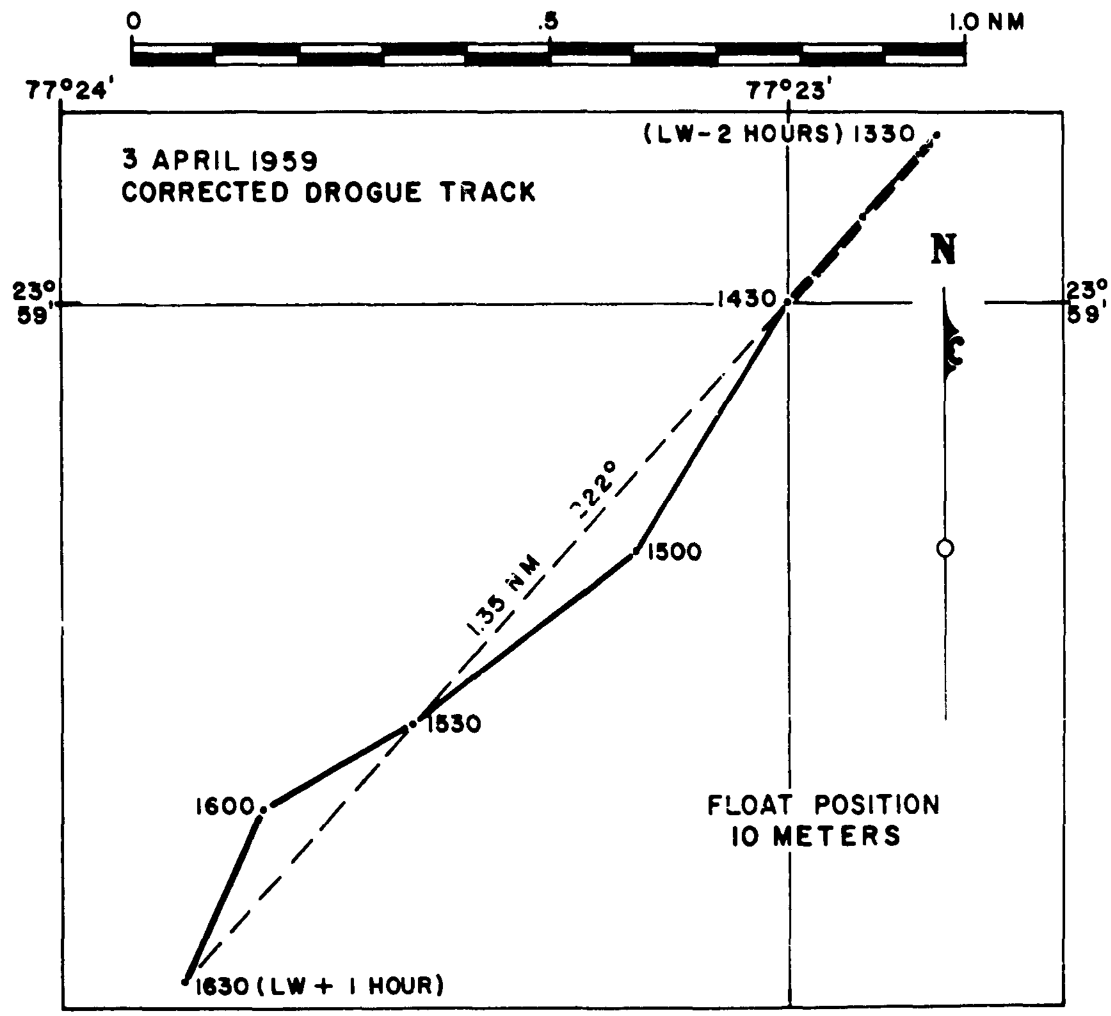


Drogue Current Observations - Area D3 - Depths 50 and 200 Meters

FIGURE A-3

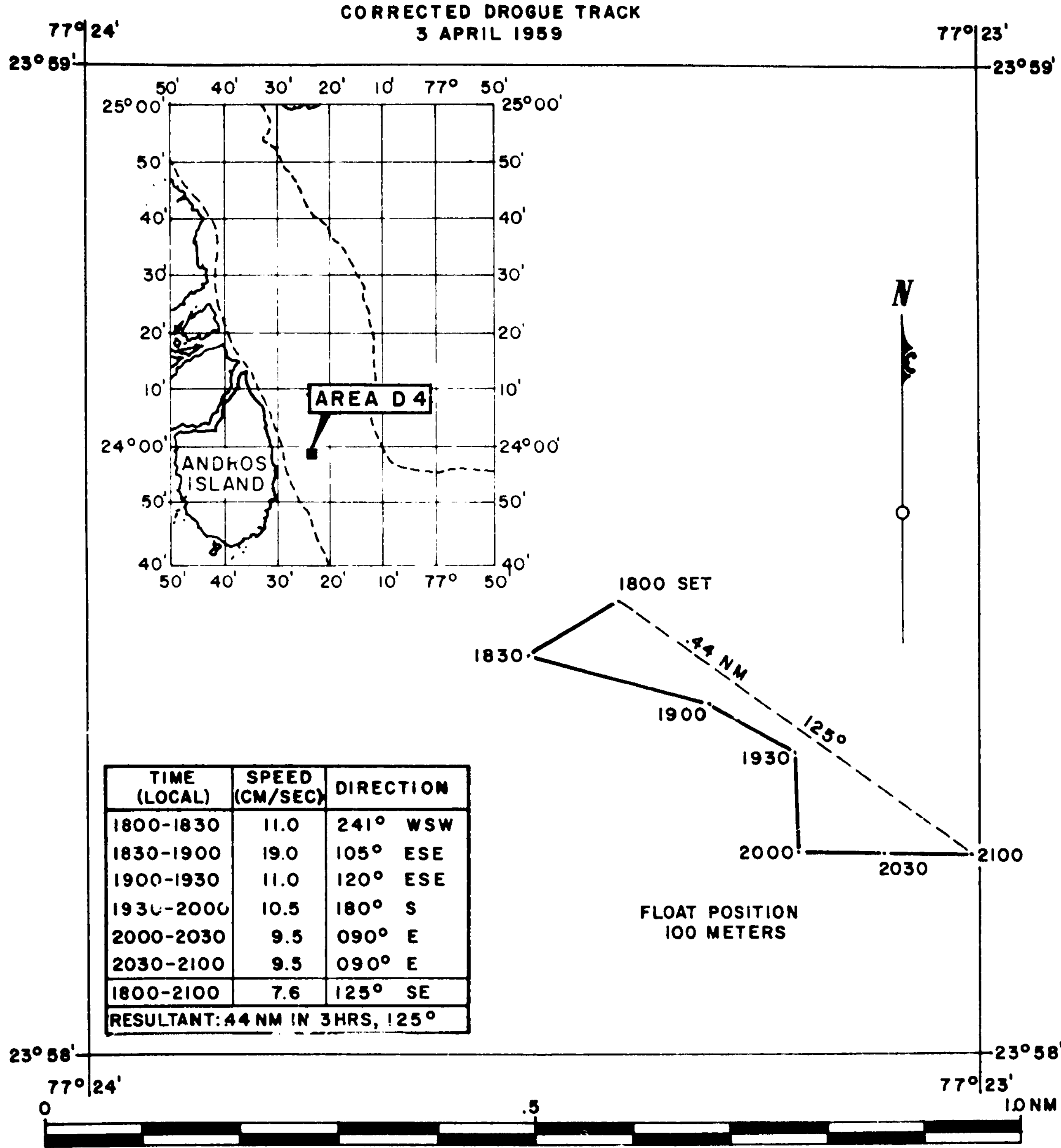


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1330-1400	14.0	222° SW
1400-1430	14.0	222° SW
1430-1500	36.0	211° SSW
1500-1530	34.5	234° SW
1530-1600	21.0	242° WSW
1600-1630	22.5	204° SSW
1330-1630	23.0	222° SW
RESULTANT: 1.35 NM IN 3 HRS, 222°		



Drogue Current Observations - Area D4 - Depth 10 Meters

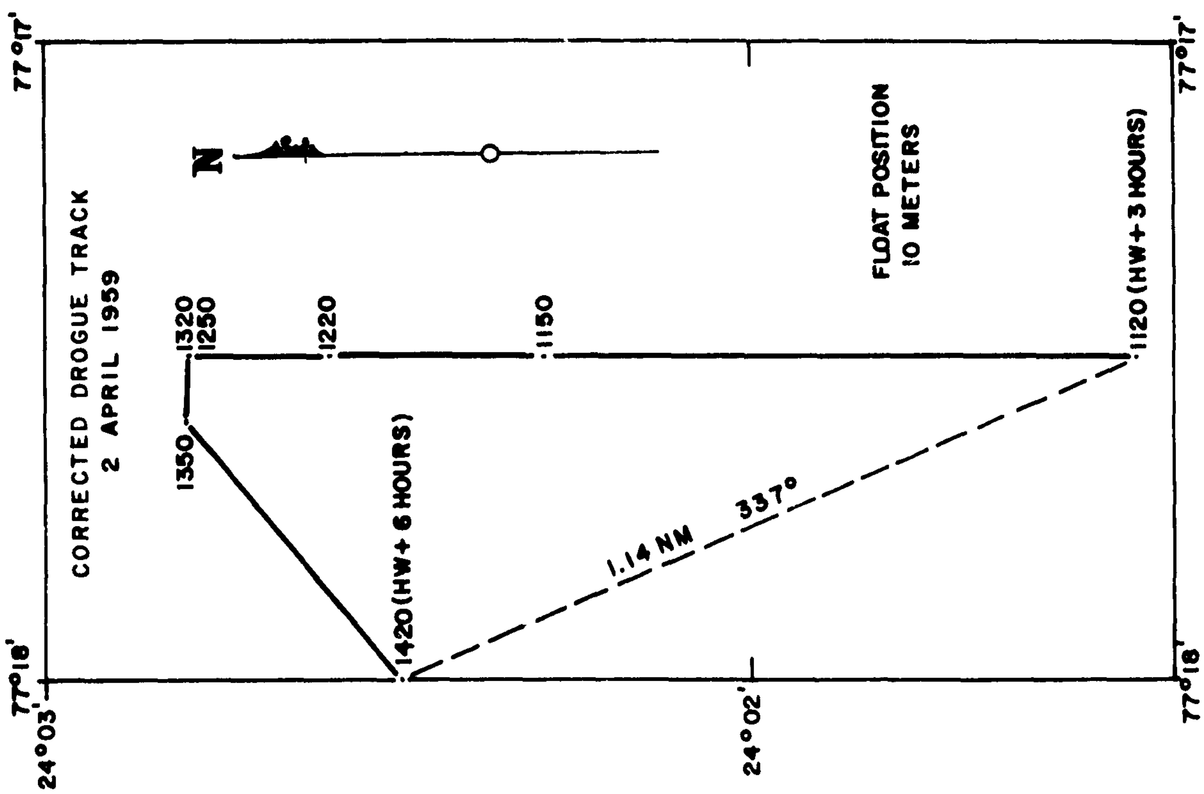
FIGURE A-4

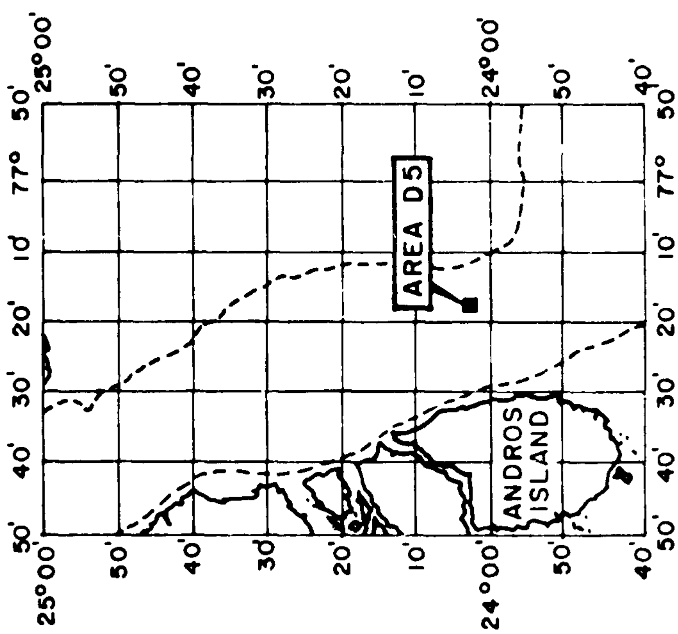


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1800-1830	11.0	241° WSW
1830-1900	19.0	105° ESE
1900-1930	11.0	120° ESE
1930-2000	10.5	180° S
2000-2030	9.5	090° E
2030-2100	9.5	090° E
1800-2100	7.6	125° SE
RESULTANT: .44 NM IN 3HRS, 125°		

Drogue Current Observations - Area D4 - Depth 100 Meters

FIGURE A-5

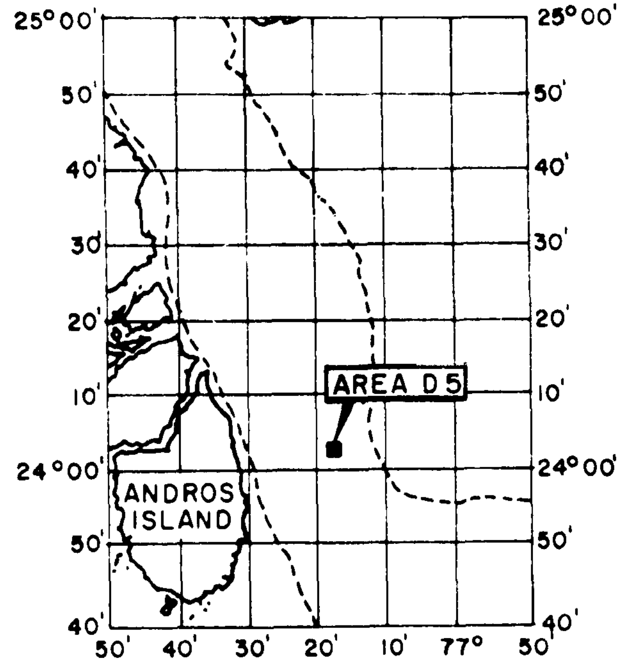




TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1120-1150	87.5	000° N.
1150-1220	30.9	000° N
1220-1250	20.6	000° N
1250-1320	00.0	—
1320-1350	9.5	270° W
1350-1420	48.5	230° SW
1120-1420	19.5	337° NNW
RESULTANT: 1.14 NM IN 3 HRS, 337°		

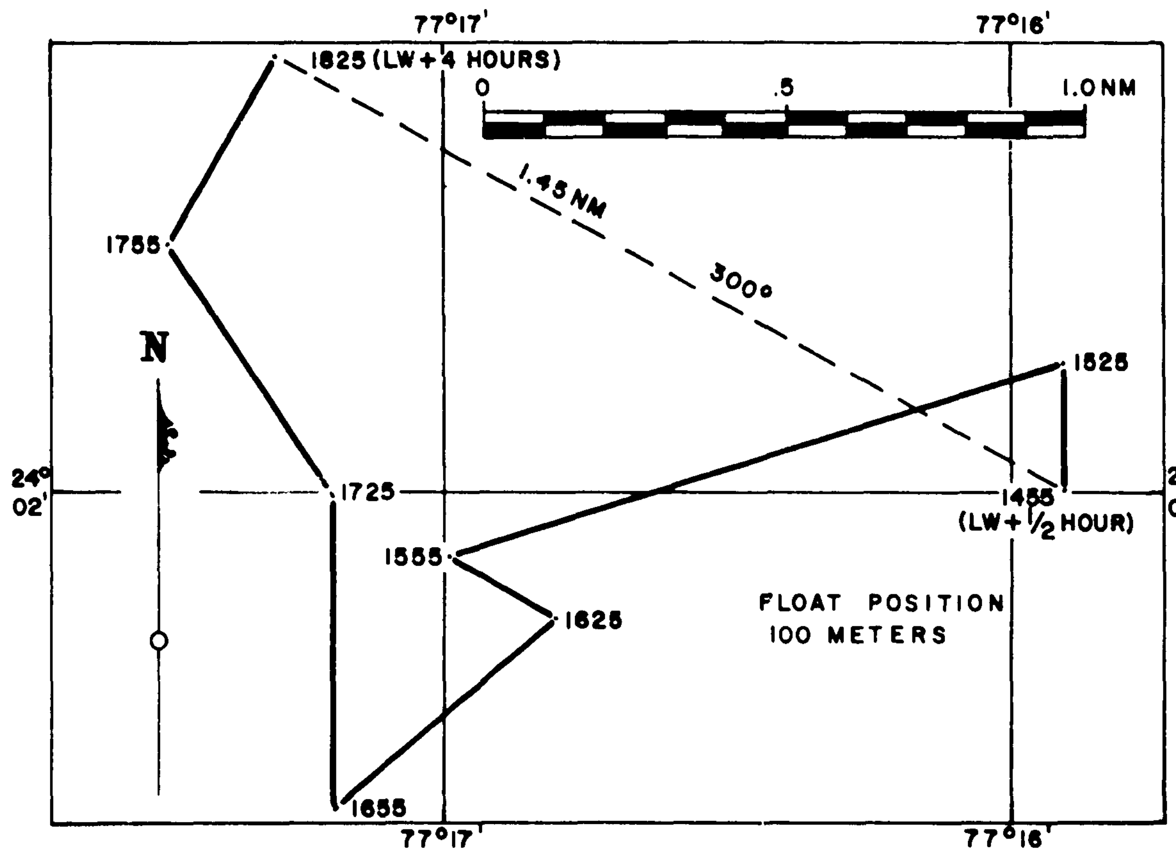
Drogue Current Observations - Area D5 - Depth 10 Meters

FIGURE A-6



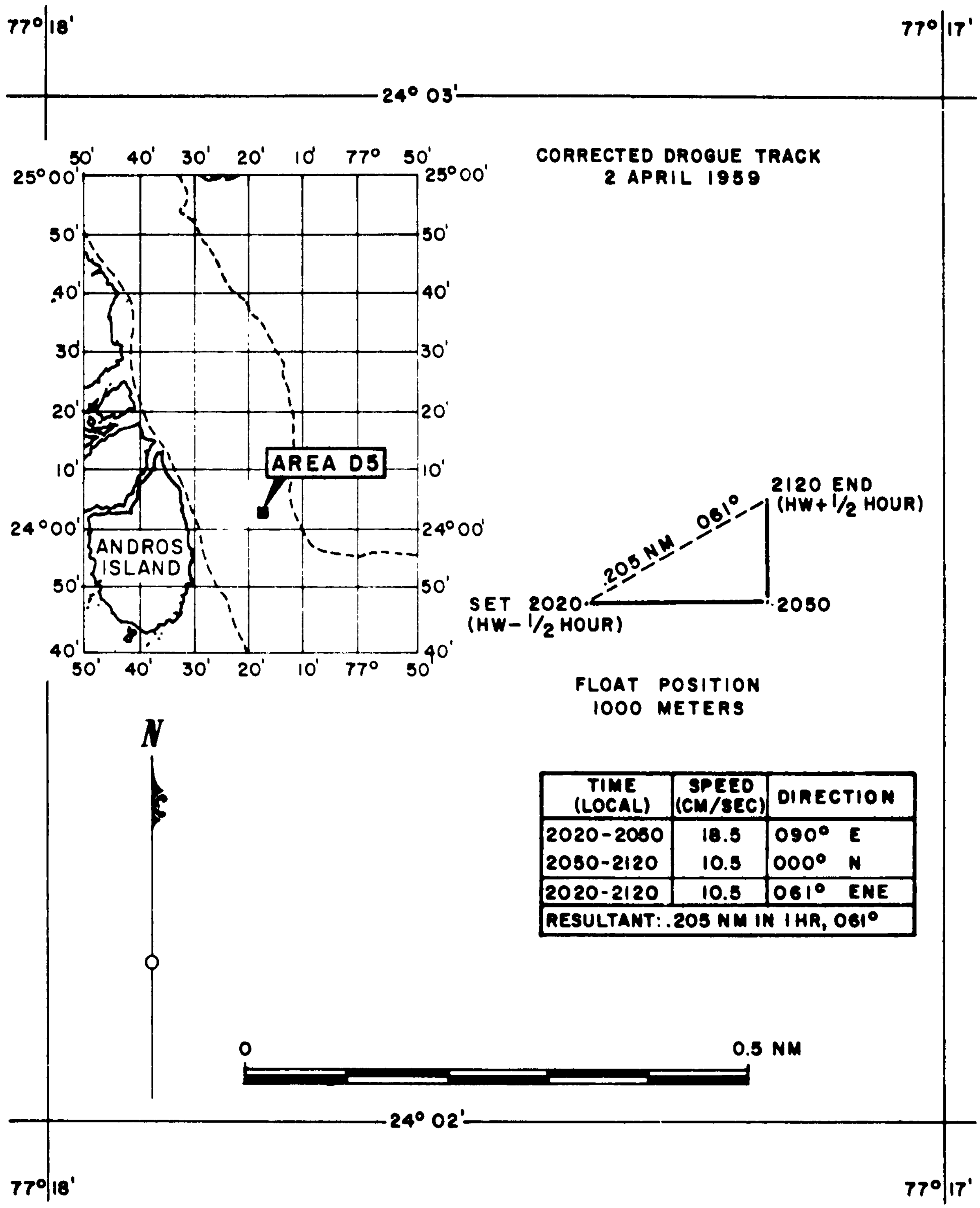
TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1455 - 1525	20.5	000° N
1525 - 1555	10 .0	253° WSW
1555 - 1625	21.0	119° ESE
1625 - 1655	48.5	230° SW
1655 - 1725	51.5	000° N
1725 - 1755	50.0	326° SW
1755 - 1825	36.5	031° NNE
1455 - 1825	21.0	300° WNW
RESULTANT: 1.45 NM IN 3½ HRS, 300°		

CORRECTED DROGUE TRACK
2 APRIL 1959



Drogue Current Observations - Area D5 - Depth 100 Meters

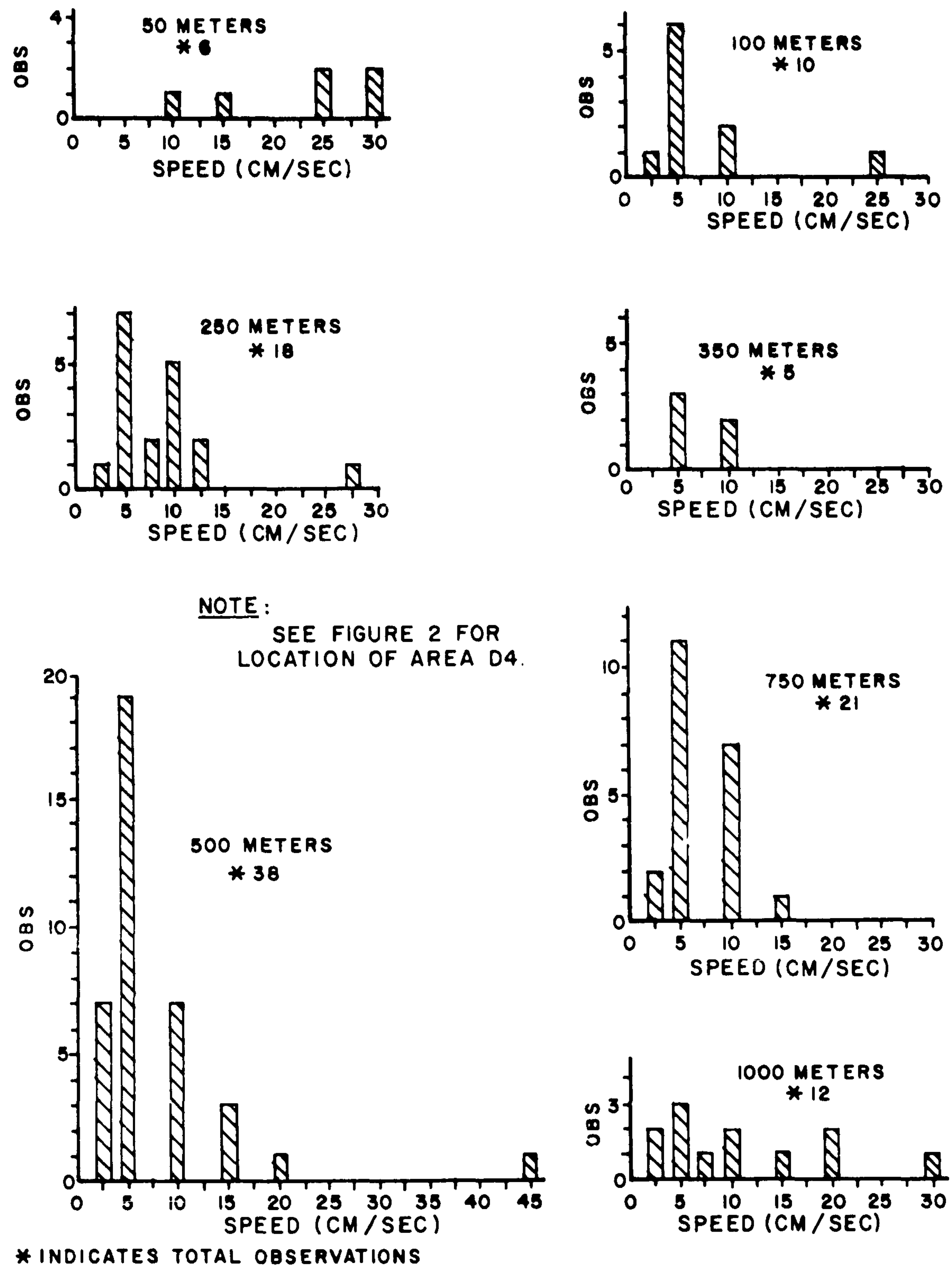
FIGURE A-7



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
2020-2050	18.5	090° E
2050-2120	10.5	000° N
2020-2120	10.5	061° ENE
RESULTANT: .205 NM IN 1 HR, 061°		

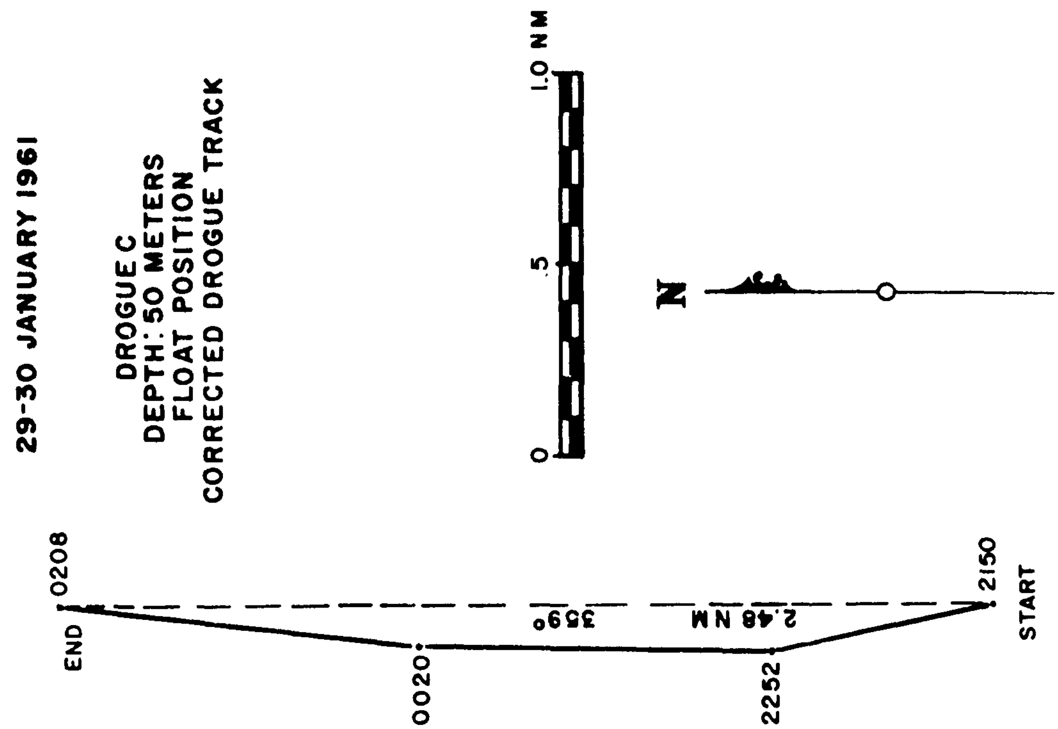
Drogue Current Observations - Area D5 - Depth 1000 Meters

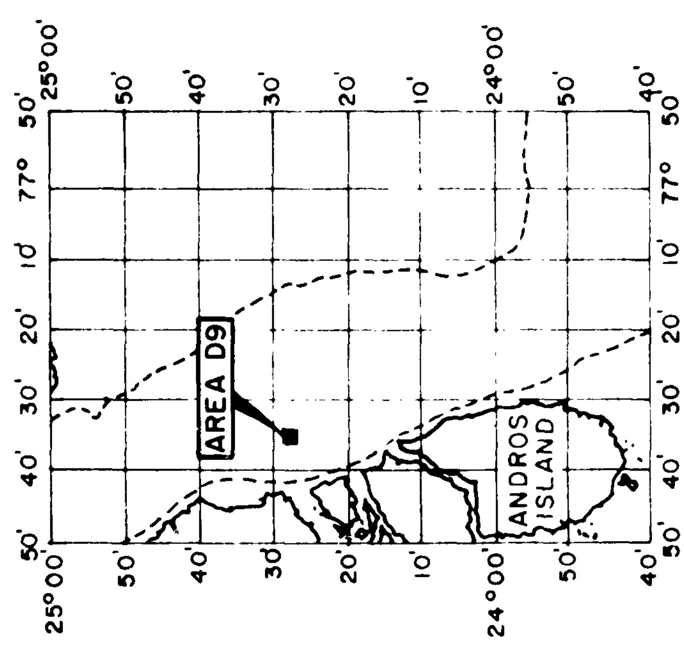
FIGURE A-8



Frequency of Occurance of Current Speeds - Area D6

FIGURE A-9

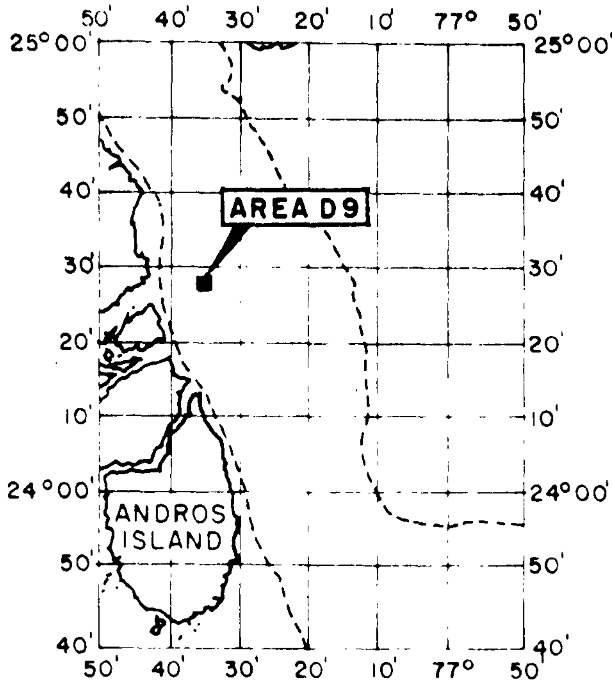


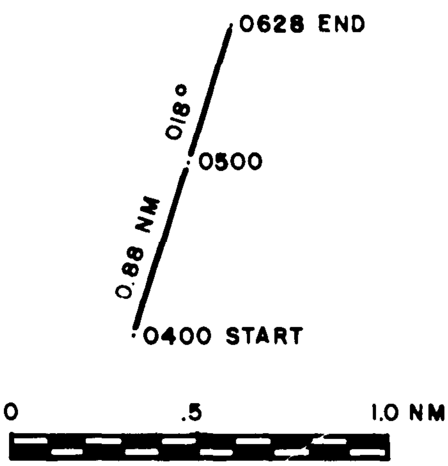


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
2150-2252	31.0	347° NNW
2252-0020	31.0	360° N
0020-0208	25.5	005° N
2150-0208	29.7	359° N
RESULTANT: 2.48 NM IN 4.3 HRS, 359°		

Drogue Current Observations - Area D9 - Depth 50 Meters - Drogue C

FIGURE A-10



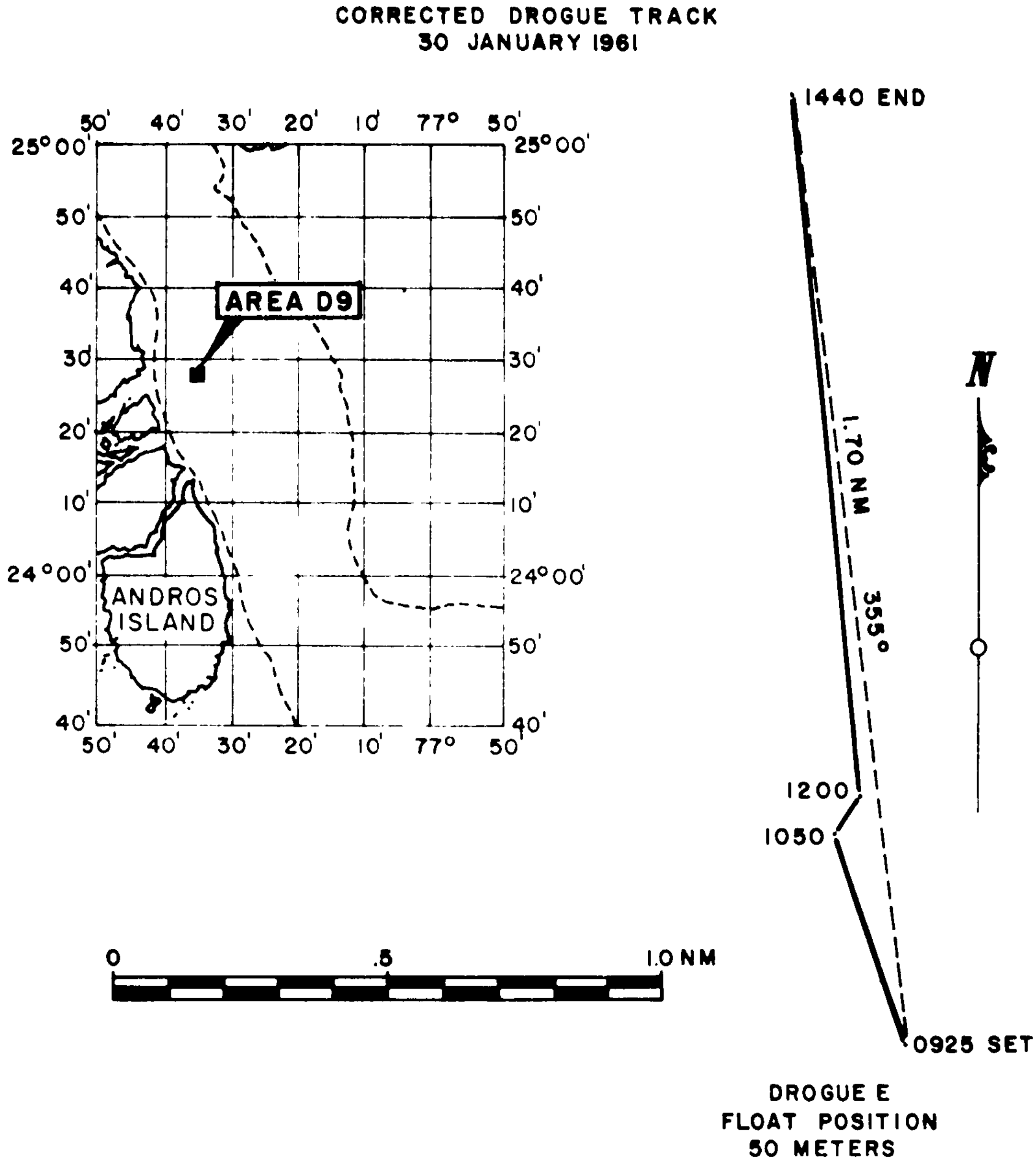


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0400-0500	25.5	018° NNE
0500-0628	10.5	018° NNE
0400-0628	18.3	018° NNE
RESULTANT: 0.88 NM IN 2.47 HRS, 018°		

DROGUE D
CORRECTED DROGUE TRACK
FLOAT POSITION
30 JANUARY 1961
50 METERS

Drogue Current Observations - Area D9 - Depth 50 Meters - Drogue D

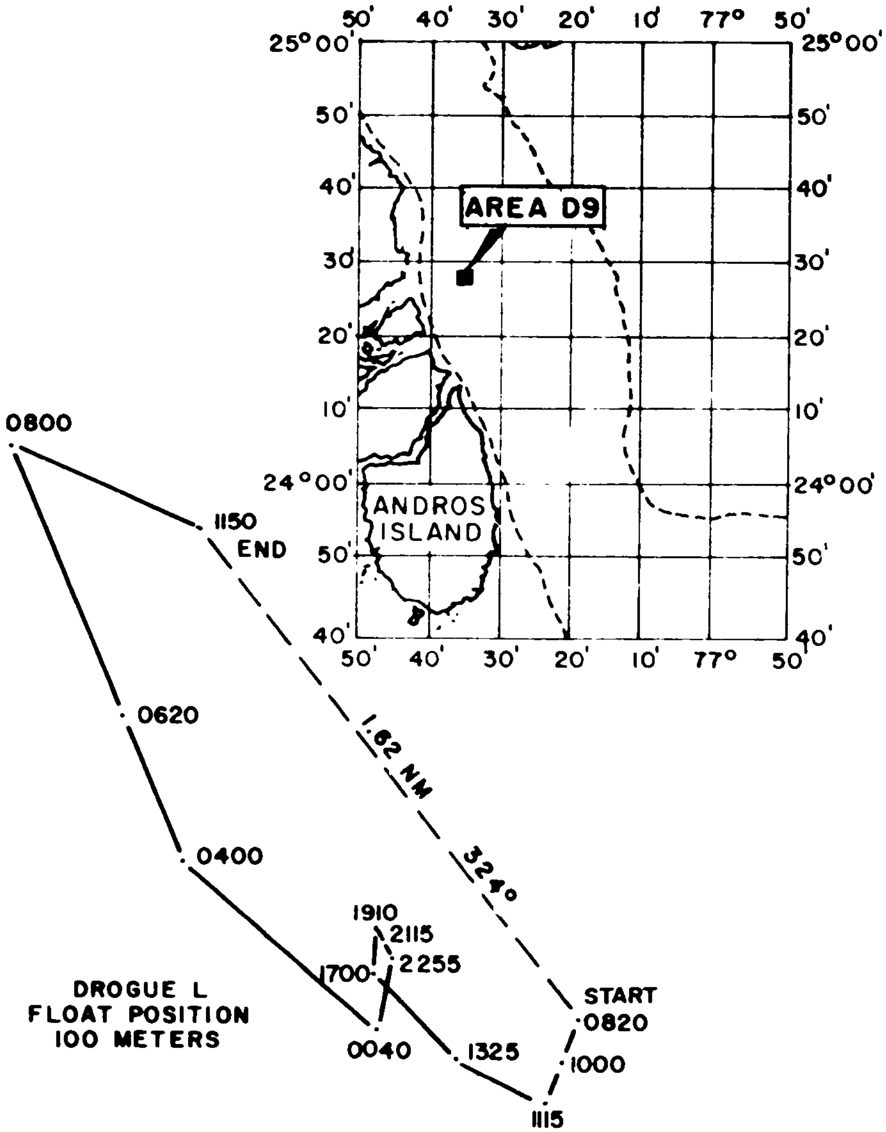
FIGURE A-11



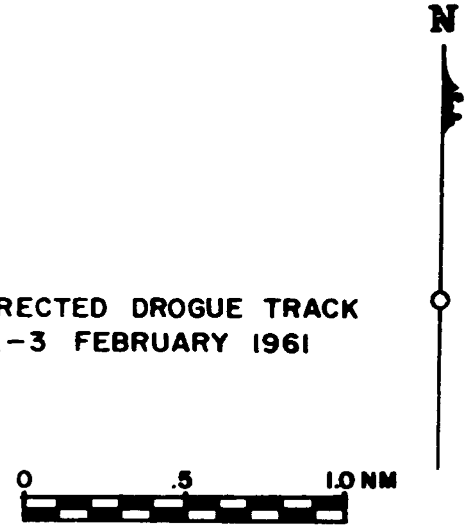
TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0925-1050	14.4	345° NNW
1050-1200	3.6	040° NE
1200-1440	24.2	357° N
0925-1440	16.5	355° N
RESULTANT: 1.70 NM IN 5.3 HRS, 355°		

Drogue Current Observations - Area D9 - Depth 50 Meters - Drogue E

FIGURE A-12



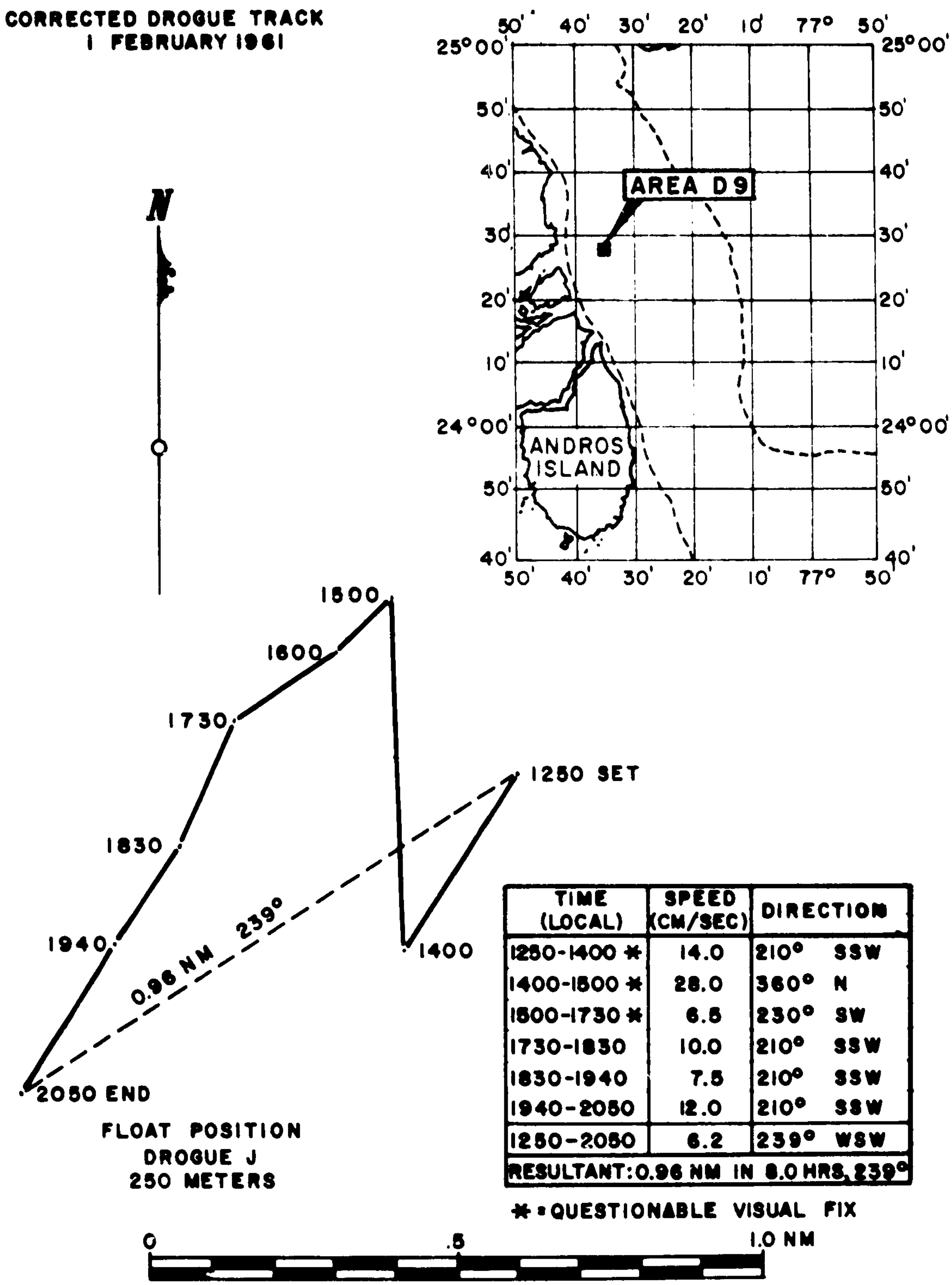
CORRECTED DROGUE TRACK
2-3 FEBRUARY 1961



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0820-1115	5.0	200° SSW
1115-1325	5.0	295° WNW
1325-1700	5.0	315° NW
1700-1910	5.0	005° N
1910-2255	2.5	155° SSE
2255-0040	5.0	190° S
0040-0400	10.0	310° NW
0400-0620	10.0	340° NNW
0620-0800	25.5	340° NNW
0800-1150	5.0	114° ESE
0820-1150	8.0	324° NW
RESULTANT: 1.62 NM IN 27.5 HRS 324°		

Drogue Current Observations - Area D9 - Depth 100 Meters - Drogue L

FIGURE A-13



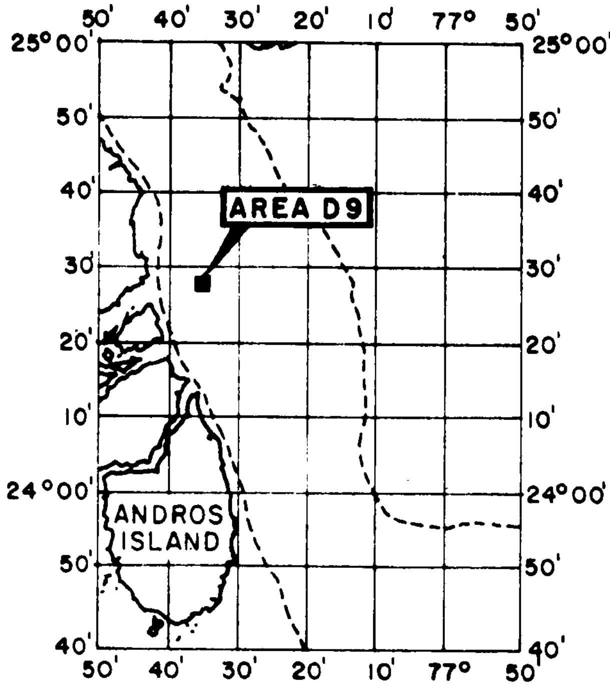
TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1250-1400 *	14.0	210° SSW
1400-1500 *	28.0	360° N
1500-1730 *	6.5	230° SW
1730-1830	10.0	210° SSW
1830-1940	7.5	210° SSW
1940-2050	12.0	210° SSW
1250-2050	6.2	239° WSW
RESULTANT: 0.96 NM IN 8.0 HRS, 239°		

* = QUESTIONABLE VISUAL FIX

Drogue Current Observations - Area D9 - Depth 250 Meters - Drogue J

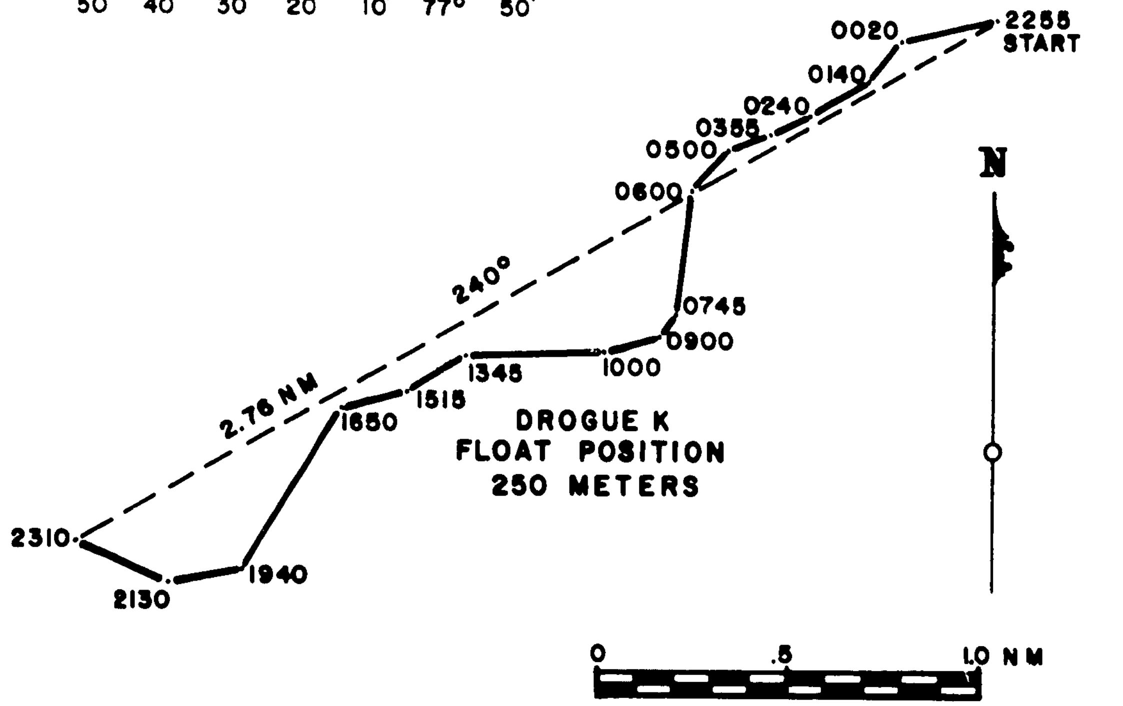
FIGURE A-14

CORRECTED DROGUE TRACK
1-2 FEBRUARY 1961



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
2255-0020	10.0	260° W
0020-0140	5.0	220° SW
0140-0500	5.0	245° WSW
0500-0600	5.0	220° SW
0600-0745	10.0	190° S
0745-0900	2.5	210° SSW
0900-1345	5.0	265° W
1345-1650	5.0	245° WSW
1650-1940	5.0	210° SSW
1940-2130	5.0	260° W
2130-2310	10.0	290° W
2255-2310	5.8	240° WSW

RESULTANT: 2.76 NM IN 24.3 HRS 240°

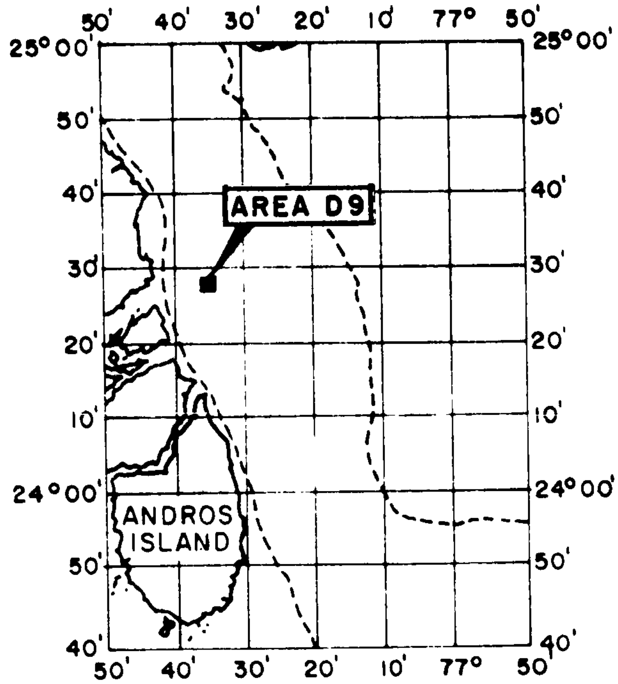


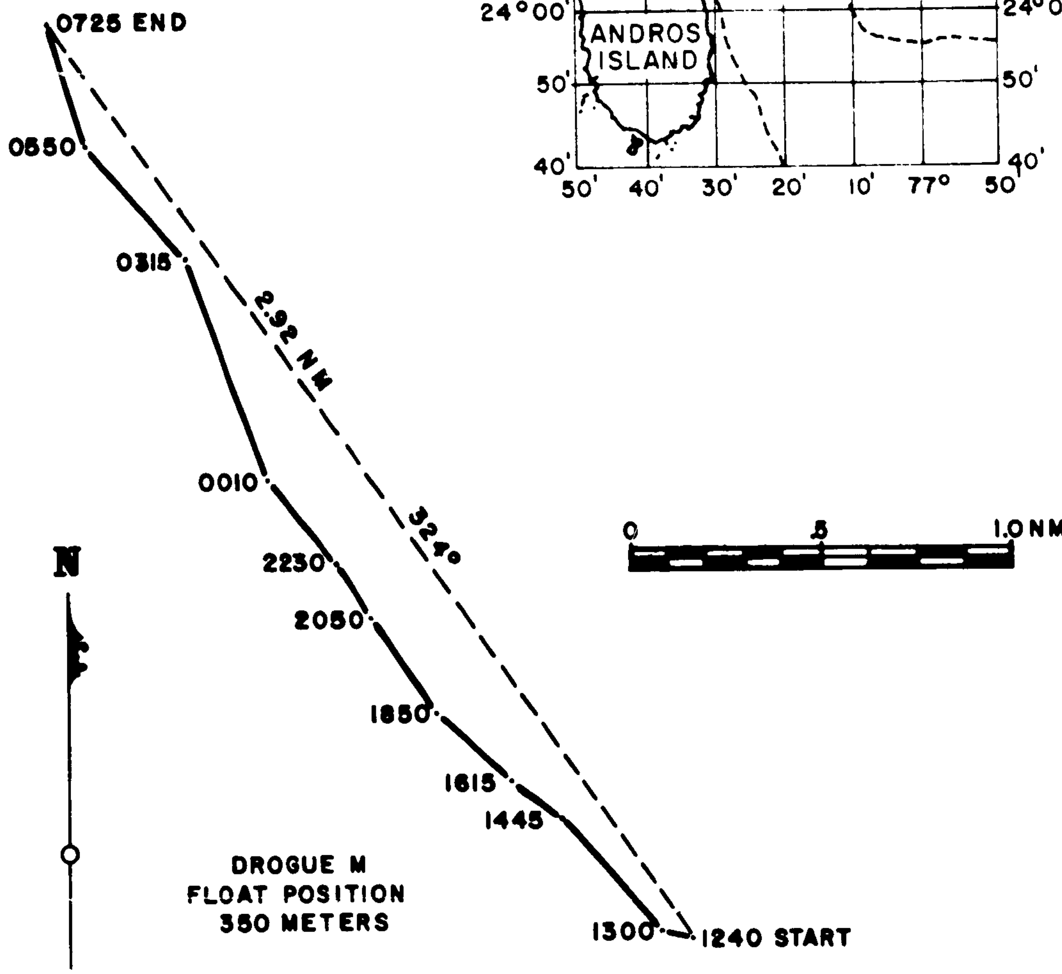
Drogue Current Observations - Area D9 - Depth 250 Meters - Drogue K

FIGURE A-15

TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1300-1850	5.0	320° NW
1850-0010	5.0	330° NNW
0010-0315	10.0	340° NNW
0315-0550	5.0	320° NW
0550-0725	10.0	340° NNW
1300-0725	8.2	325° NW
RESULTANT: 2.92 NM IN 18.4 HRS, 325°		

CORRECTED DROGUE TRACK
2-3 FEBRUARY 1961

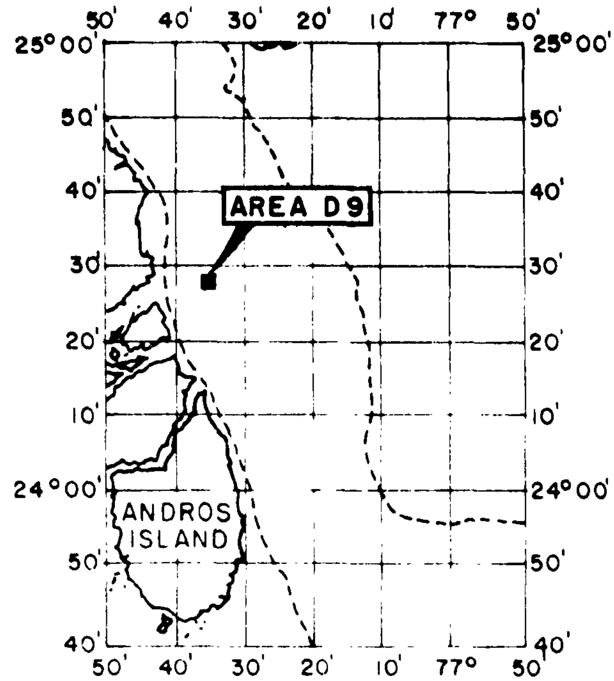




Drogue Current Observations - Area D9 - Depth 350 Meters - Drogue M

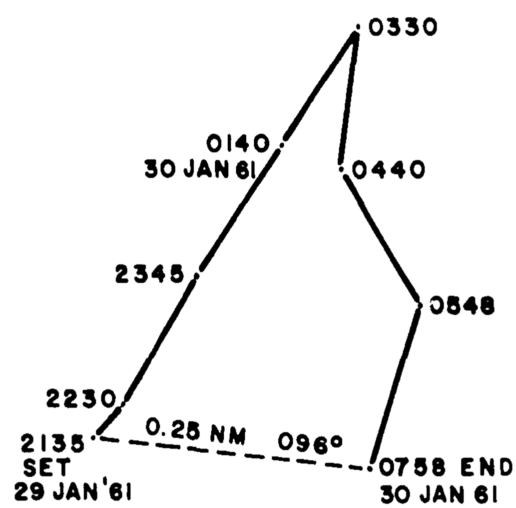
FIGURE A-16

CORRECTED DROGUE TRACK
29-30 JANUARY 1961



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
2135-2230	< 2.5	045° NE
2230-2345	5.0	045° NE
2345-0140	2.5	045° NE
0140-0330	2.5	045° NE
0330-0440	5.0	183° S
0440-0548 *	5.0	150° SSE
0548-0758 *	2.5	197° SSW
2135-0758	1.2	096° E
RESULTANT: 0.25 NM IN 10.4 HRS, 096°		

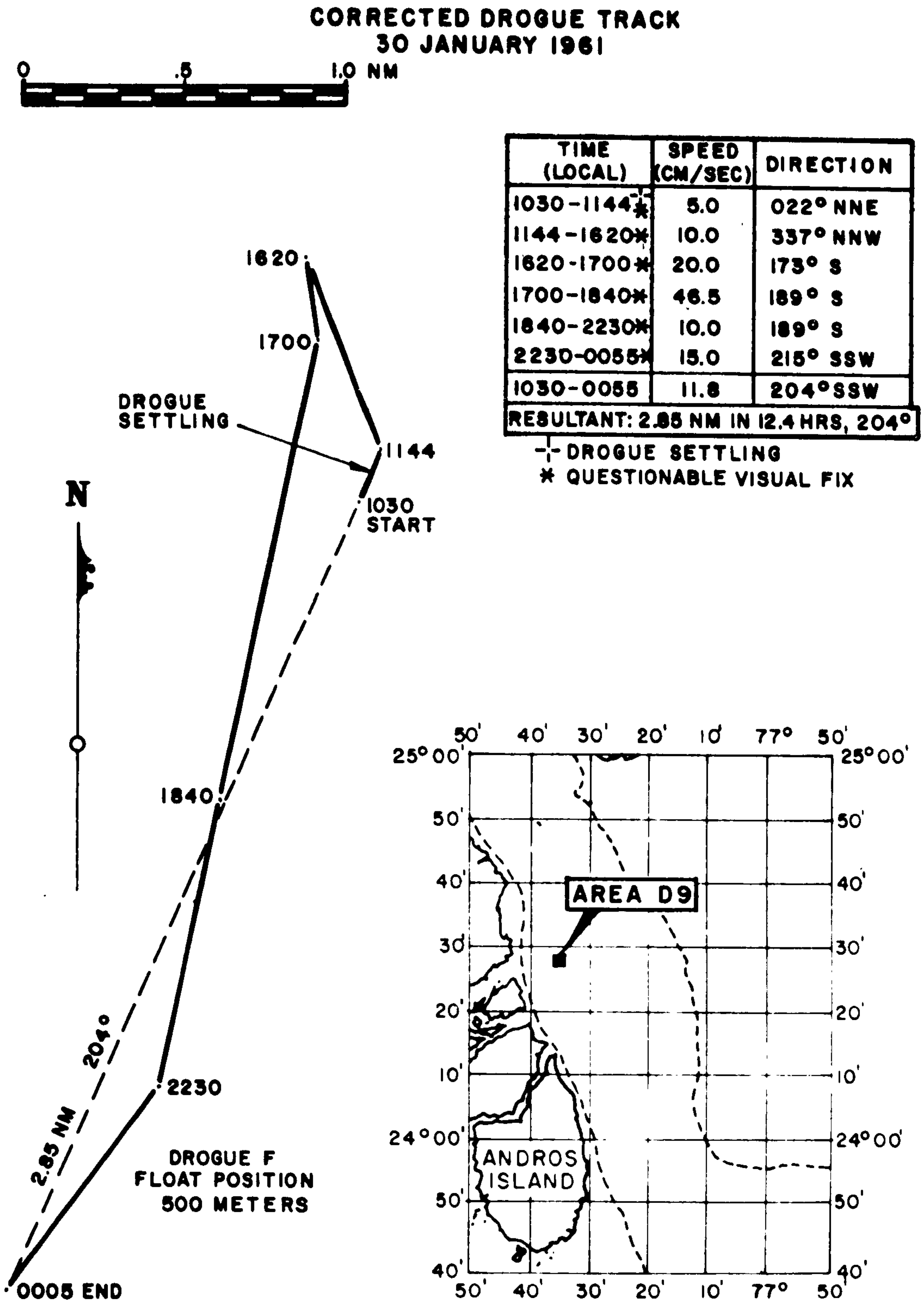
*=QUESTIONABLE VISUAL FIX



DROGUE B
FLOAT POSITION
500 METERS

Drogue Current Observations - Area D9 - Depth 500 Meters - Drogue B

FIGURE A-17



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1030-1144 -¦-*	5.0	022° NNE
1144-1620*	10.0	337° NNW
1620-1700*	20.0	173° S
1700-1840*	46.5	189° S
1840-2230*	10.0	189° S
2230-0055*	15.0	215° SSW
1030-0055	11.8	204° SSW
RESULTANT: 2.85 NM IN 12.4 HRS, 204°		

-¦- DROGUE SETTLING
* QUESTIONABLE VISUAL FIX

Drogue Current Observations - Area D9 - Depth 500 Meters - Drogue F

FIGURE A-18

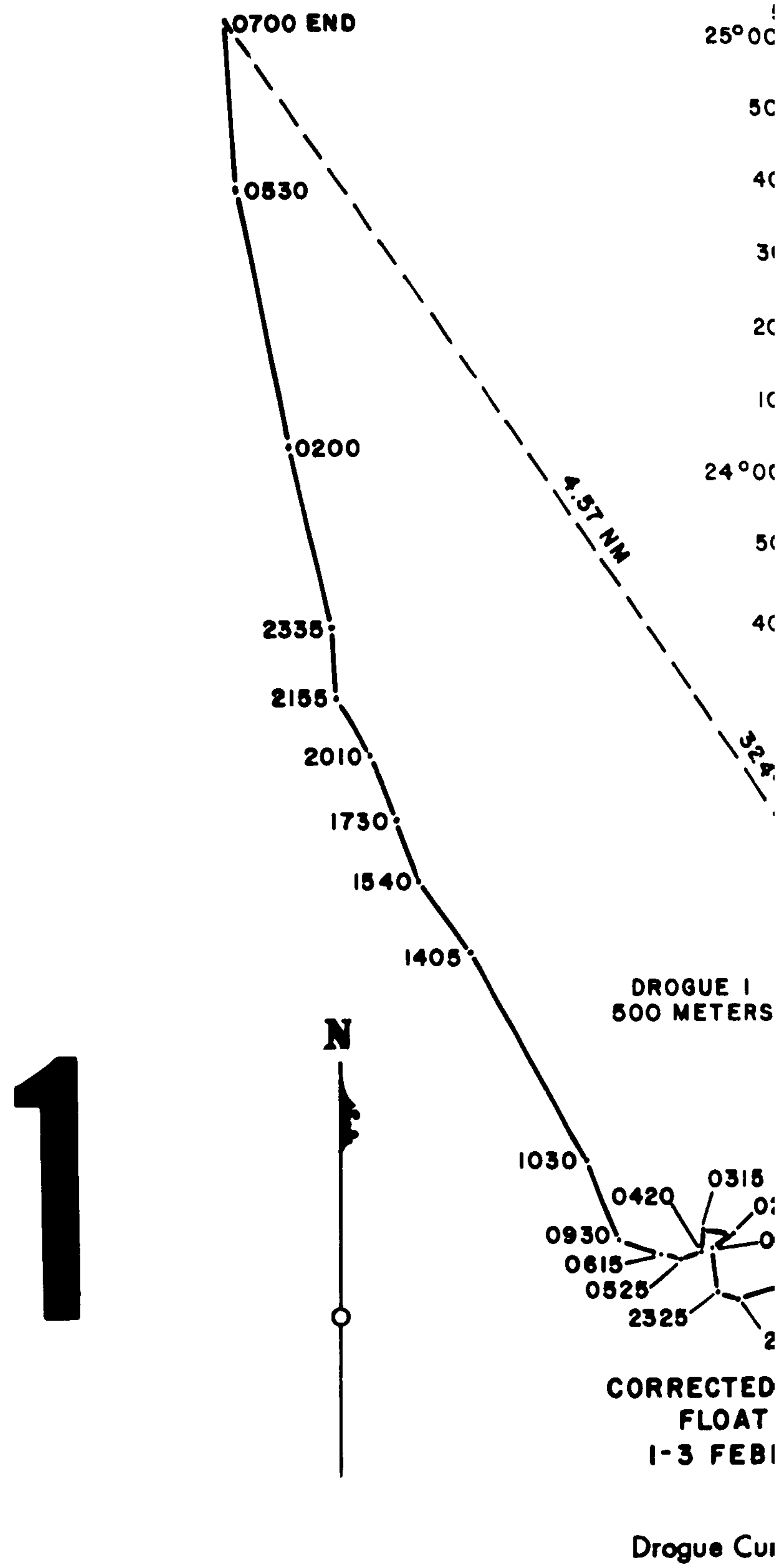
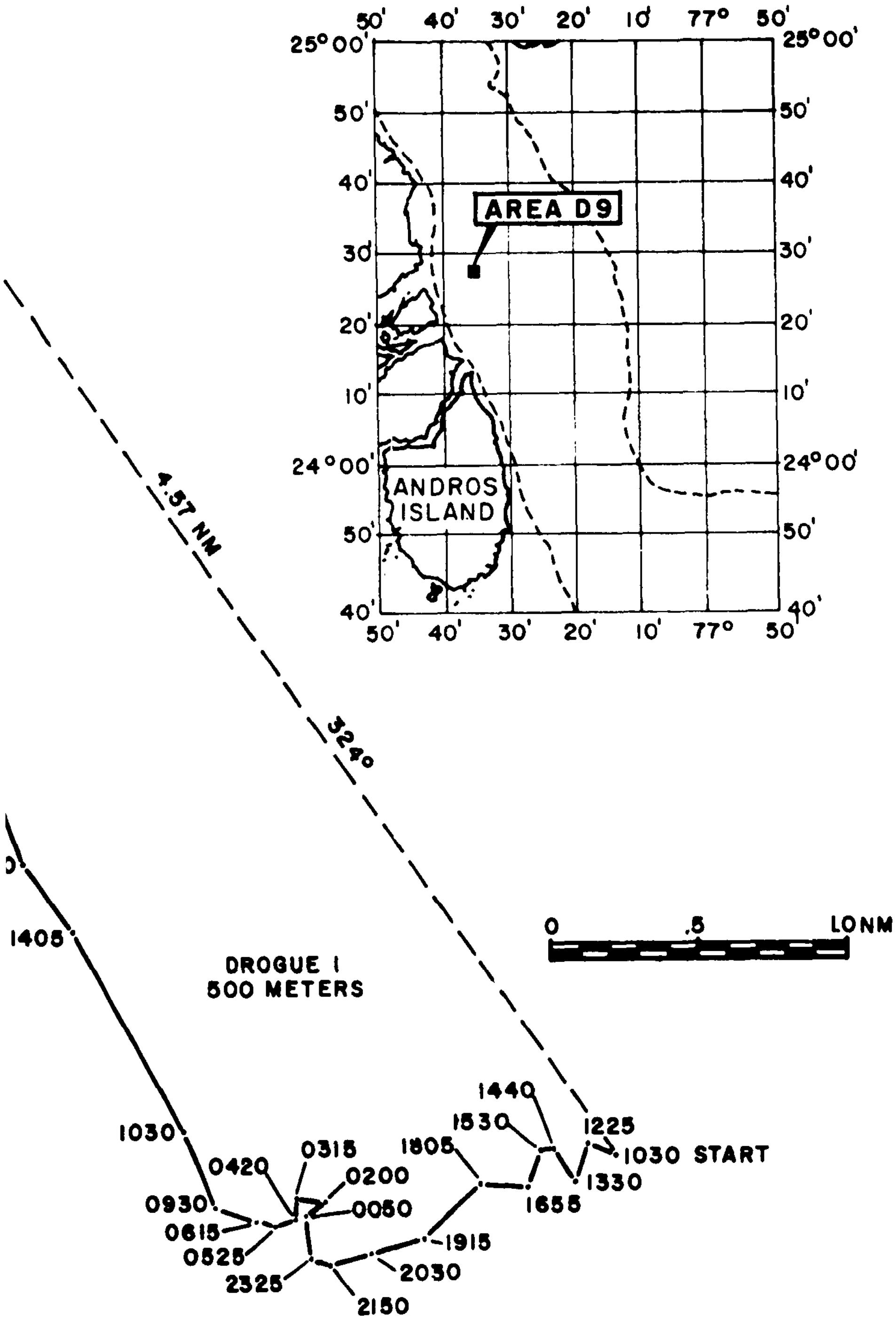

0700 END
25°00
50
40
30
20
10
0530
0200
24°00
4.57 NM
50
40
2335
2155
2010
1730
1540
1405
DROGUE I
500 METERS
N
1
1030
0420
0315
0930
0615
0525
2325
CORRECTED
FLOAT
1-3 FEB
Drogue Cu

FIGURE A-19

2



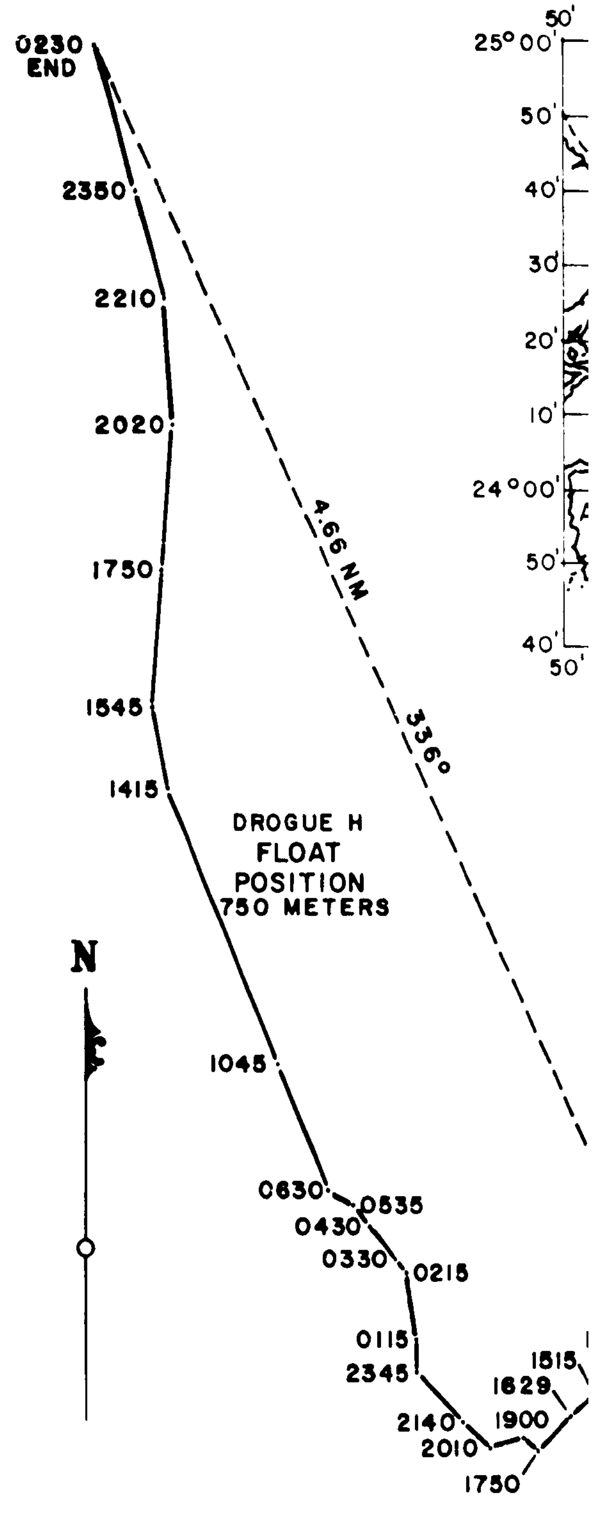
CORRECTED DROGUE TRACK
FLOAT POSITION
1-3 FEBRUARY 1961

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1030 - 1225	2.5	295 WNW
1225 - 1330	5.0	195 SSW
1330 - 1440	5.0	330 NNW
1440 - 1530	2.5	W
1530 - 1655	5.0	200 SSW
1655 - 1805	5.0	275 W
1805 - 1915	10.0	230 SW
1915 - 2150	5.0	255 WSW
2150 - 2325	2.5	255 WSW
2325 - 0050	5.0	350 N
0050 - 0200	5.0	060 ENE
0200 - 0315	5.0	280 W
0315 - 0420	5.0	185 S
0420 - 0525	5.0	245 WSW
0525 - 0930	5.0	285 WNW
0930 - 1030	15.0	340 NNW
1030 - 1540	10.0	330 NNW
1540 - 1730	5.0	320 NW
1730 - 2010	5.0	340 NNW
2010 - 2155	5.0	330 NNW
2155 - 2335	5.0	355 N
2335 - 0200	10.0	350 N
0200 - 0530	10.0	350 N
0530 - 0700	15.0	335 WNW
1030 - 0700	5.3	324 NW

Average Speed: 6.4 cm/sec
Resultant: 4.57 NM in 44.5 hrs, 324°

Drogue Current Observations - Area D9 - Depth 500 Meters - Drogue I

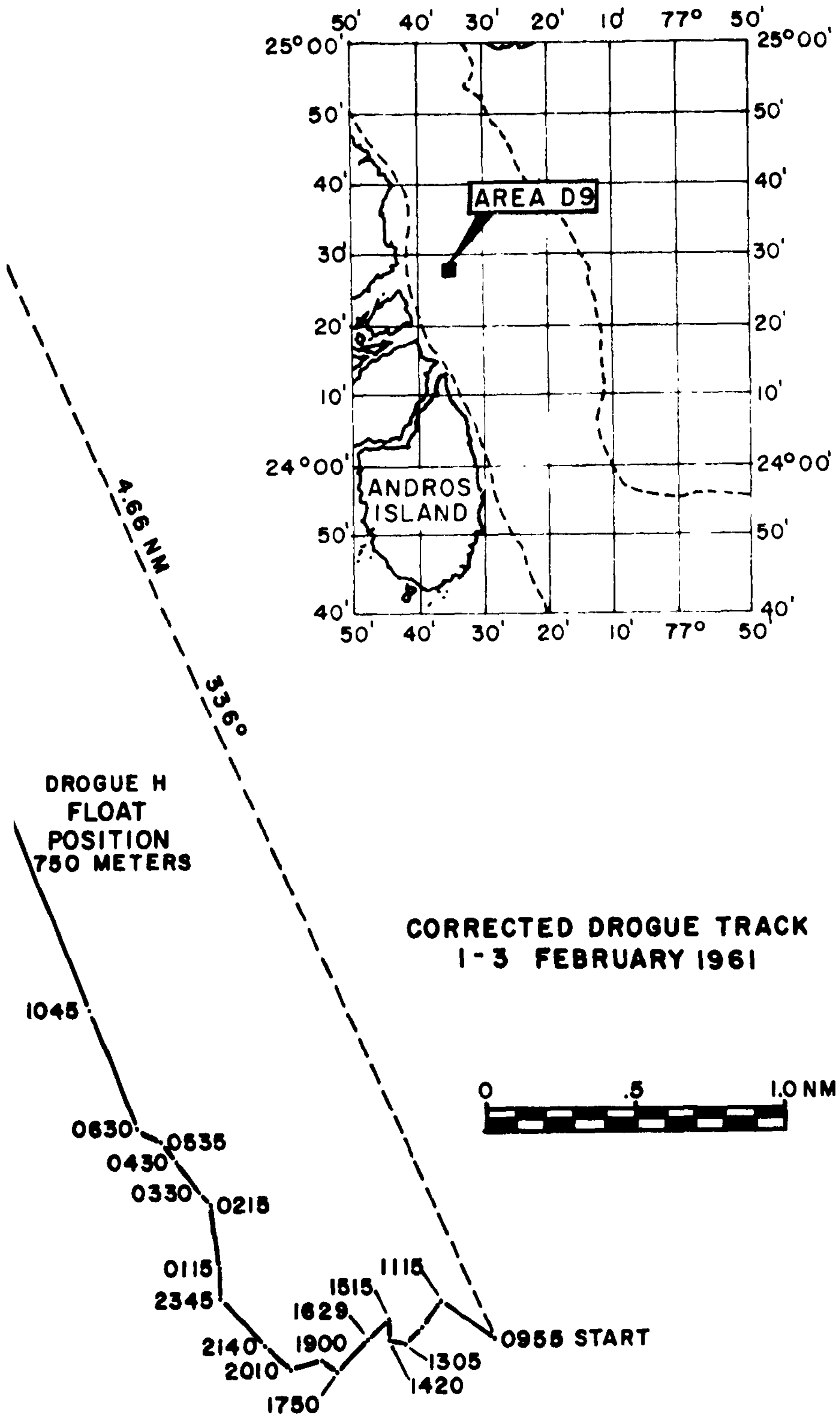
1



Drogue Curı

FIGURE A-20

2



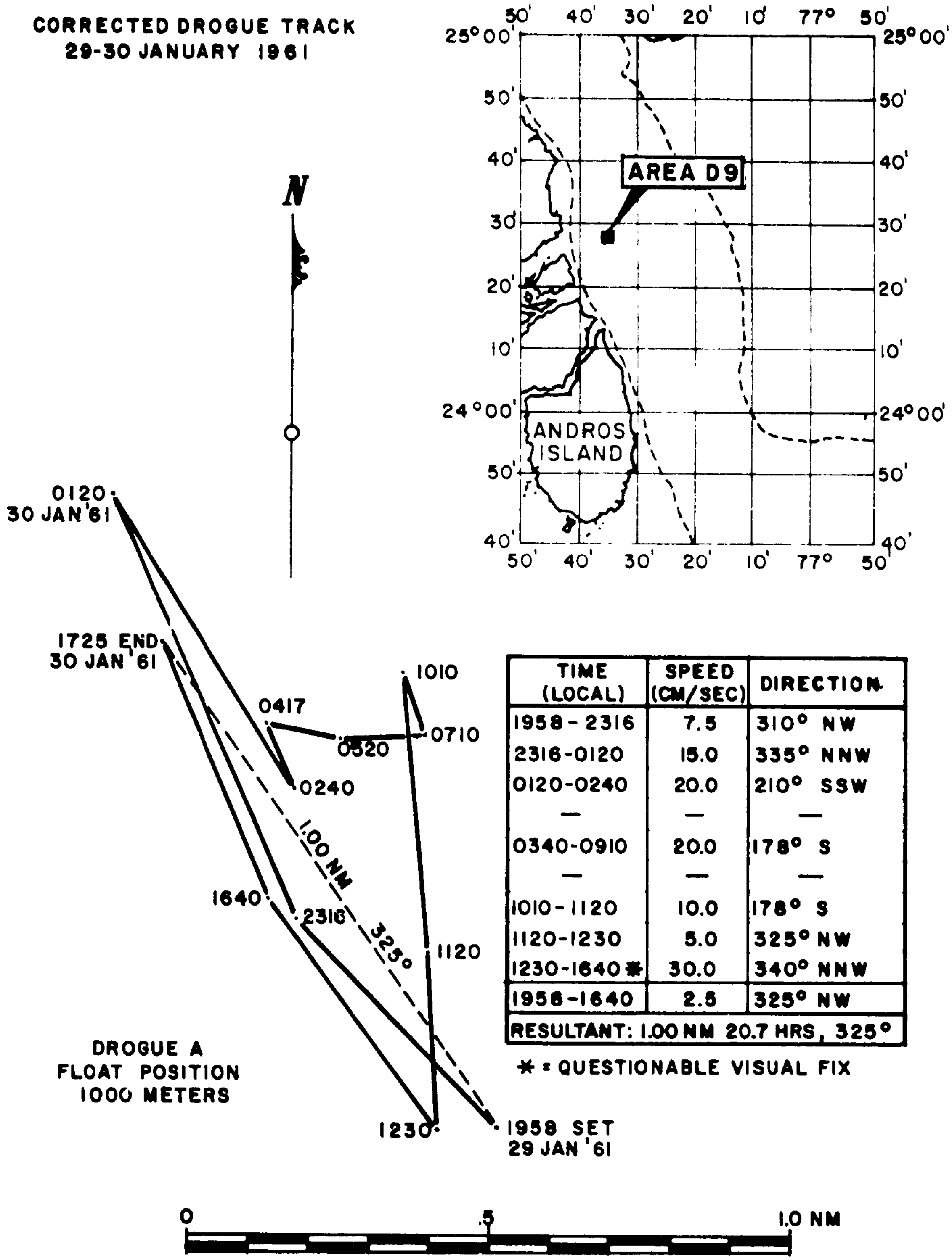
Time (Local)	Speed (cm/sec)	Direction (Degrees)
0955*- 1115	10.0	320 NW
1115 - 1305	5.0	320 NW
1305 - 1420	2.5	277 W
1420 - 1515	5.0	N
1515 - 1629	5.0	223 SW
1629 - 1750*	5.0	223 SW
1750 - 1900	5.0	320 NW
1900 - 2010	5.0	250 WSW
2010 - 2345	4.5	320 NW
2345 - 0115	5.0	350 N
0115 - 0215	10.0	350 N
0215 - 0330	2.5	320 NW
0330 - 0430	5.0	320 NW
0430 - 0630	5.0	310 NW
0630 - 1045	5.0	340 NNW
1045 - 1415	15.0	340 NNW
1415 - 1545	10.0	350 N
1545 - 1750	10.0	005 N
1750 - 2020	10.0	005 N
2020 - 2210	10.0	355 N
2210 - 2350	10.0	350 N
0955 - 2350	6.3	336 NNW

Average Speed: 6.9 cm/sec
Resultant: 4.66 NM in 37.9 hrs, 336°

*Questionable visual fix

Drogue Current Observations - Area D9 - Depth 750 Meters - Drogue H

CORRECTED DROGUE TRACK
29-30 JANUARY 1961

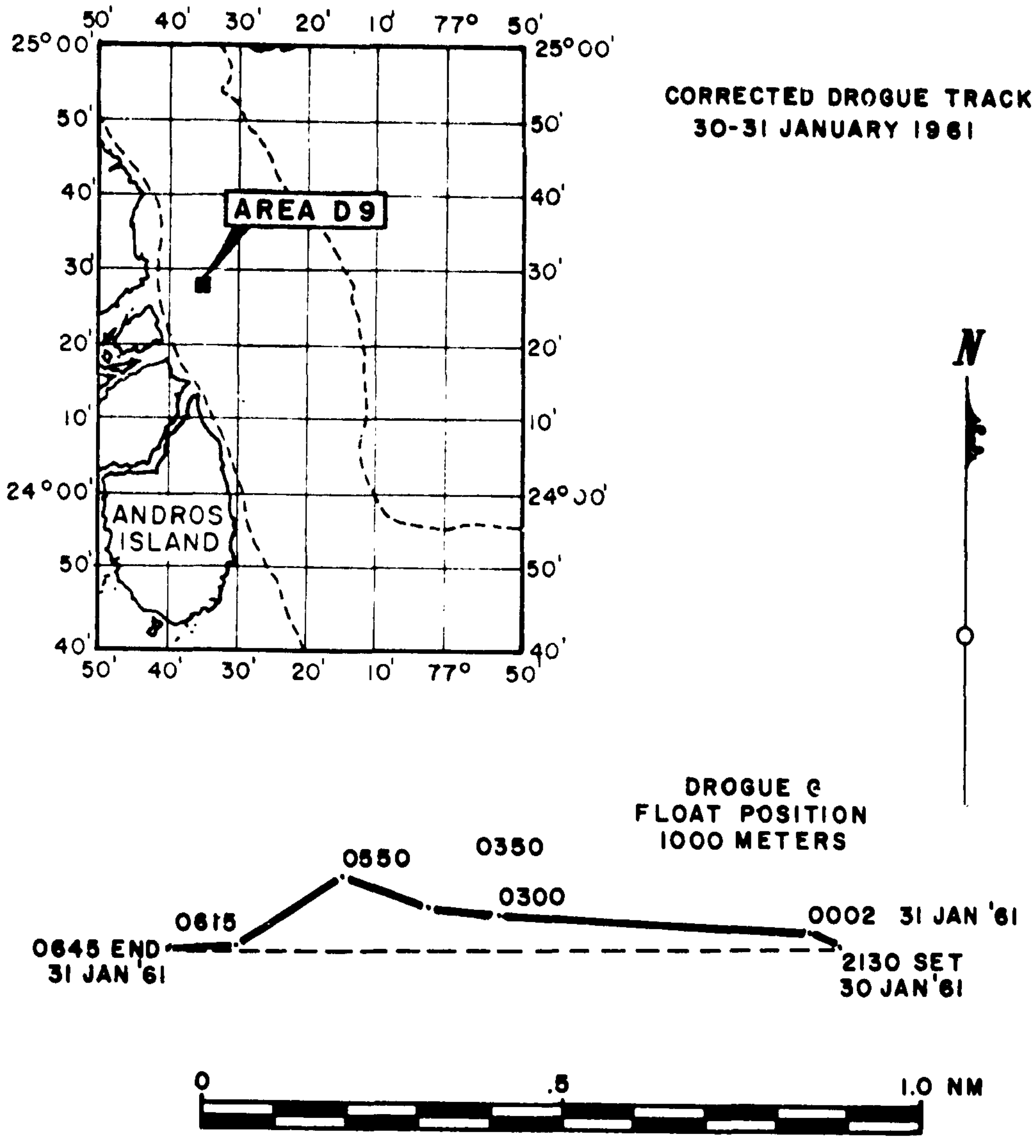


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1958-2316	7.5	310° NW
2316-0120	15.0	335° NNW
0120-0240	20.0	210° SSW
—	—	—
0340-0910	20.0	178° S
—	—	—
1010-1120	10.0	178° S
1120-1230	5.0	325° NW
1230-1640 *	30.0	340° NNW
1958-1640	2.5	325° NW
RESULTANT: 1.00 NM 20.7 HRS, 325°		

* = QUESTIONABLE VISUAL FIX

Drogue Current Observations - Area D9 - Depth 1000 Meters - Drogue A

FIGURE A-21

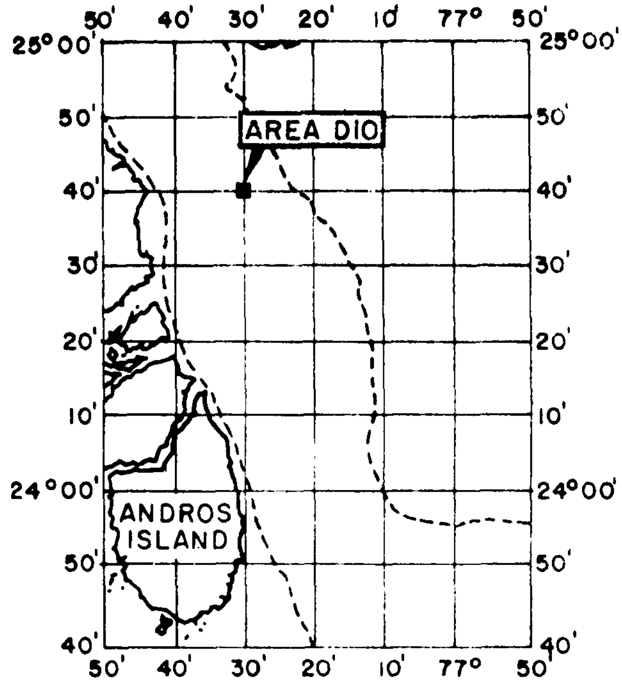


TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
2130-0002	2.5	310° NW
0002-0300	5.0	273° W
0300-0350	5.0	273° W
0350-0550	2.5	290° WNW
0550-0645	10.0	244° WSW
2130-0645	5.1	270° W
RESULTANT: 0.92 NM IN 9.3 HRS, 270°		

Drogue Current Observations - Area D9 - Depth 1000 Meters - Drogue G

FIGURE A-22

Table A-1. Drogue Current Observation Data - Area D10 - Depths 8, 100, and 500 Meters



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1000-1214	37.0	328° NNW
1214-1423	32.0	325° NNW
1423-1637	24.5	328° NNW
DROGUE RESET	—	—
2003-2322	10.0	303° WNW
2322-0231	10.0	273° W
0231-0540	12.5	221° SW
0540-0915	7.0	182° S
0915-1134	11.5	214° SSW
1134-1423	10.0	217° SW
RESULTANT:		

8 METERS
21-22 SEPTEMBER 1961

TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
1002-1210	35.5	322° NW
1210-1418	30.5	328° NNW
1418-1614	30.0	334° NNW
DROGUE RESET	—	—
2005-2319	12.5	334° NNW
2319-0223	10.0	339° NNW
0223-0525	3.5	294° WNW
0525-0840	1.5	206° SSW
0840-1120	7.5	235° SW
1120-1419	13.5	250° SW
0902-0317		
RESULTANT:		

100 METERS
21 SEPTEMBER 1961

500 METERS
22-23 SEPTEMBER 1961

TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0902-1118	8.0	255° WSW
1118-1413	5.0	284° WNW
1413-1816	6.0	205° SSW
1816-2113	6.0	240° WSW
2113-0016	4.5	274° W
0016-0317	10.0	224° SW
0902-0317		
RESULTANT:		

1

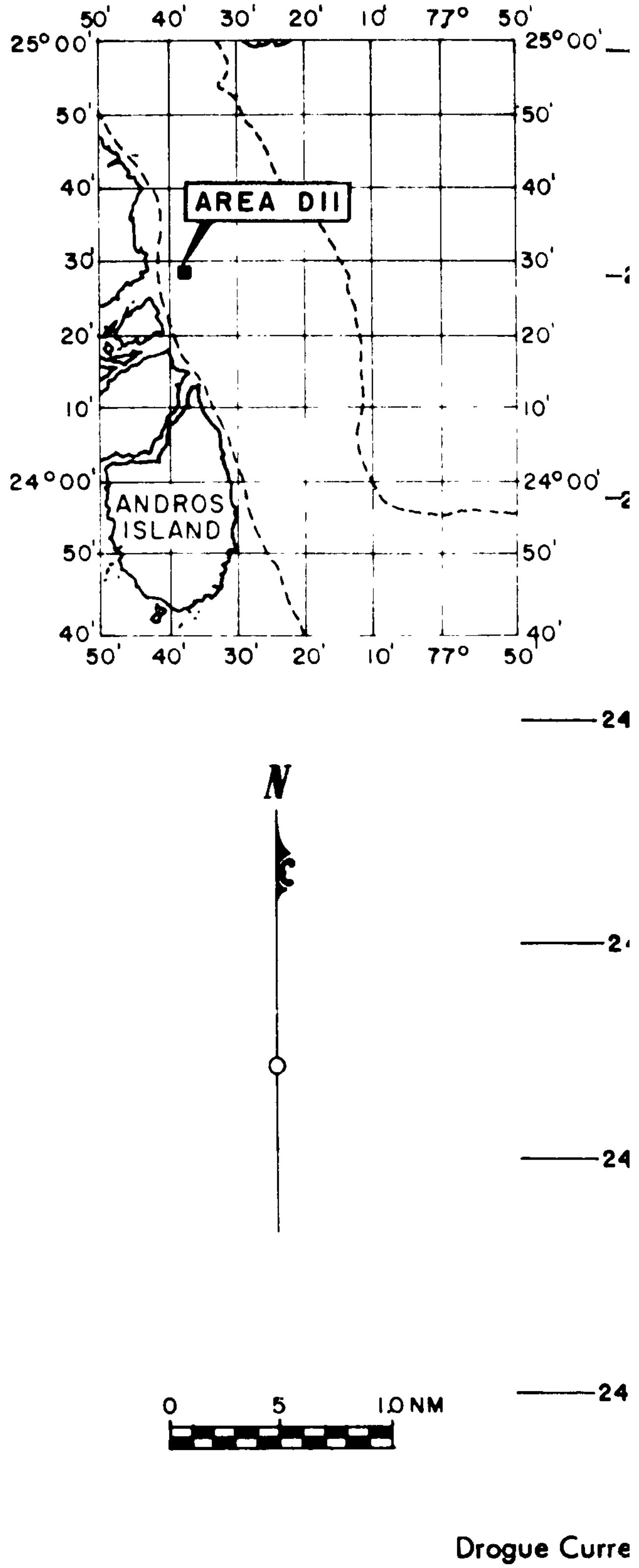
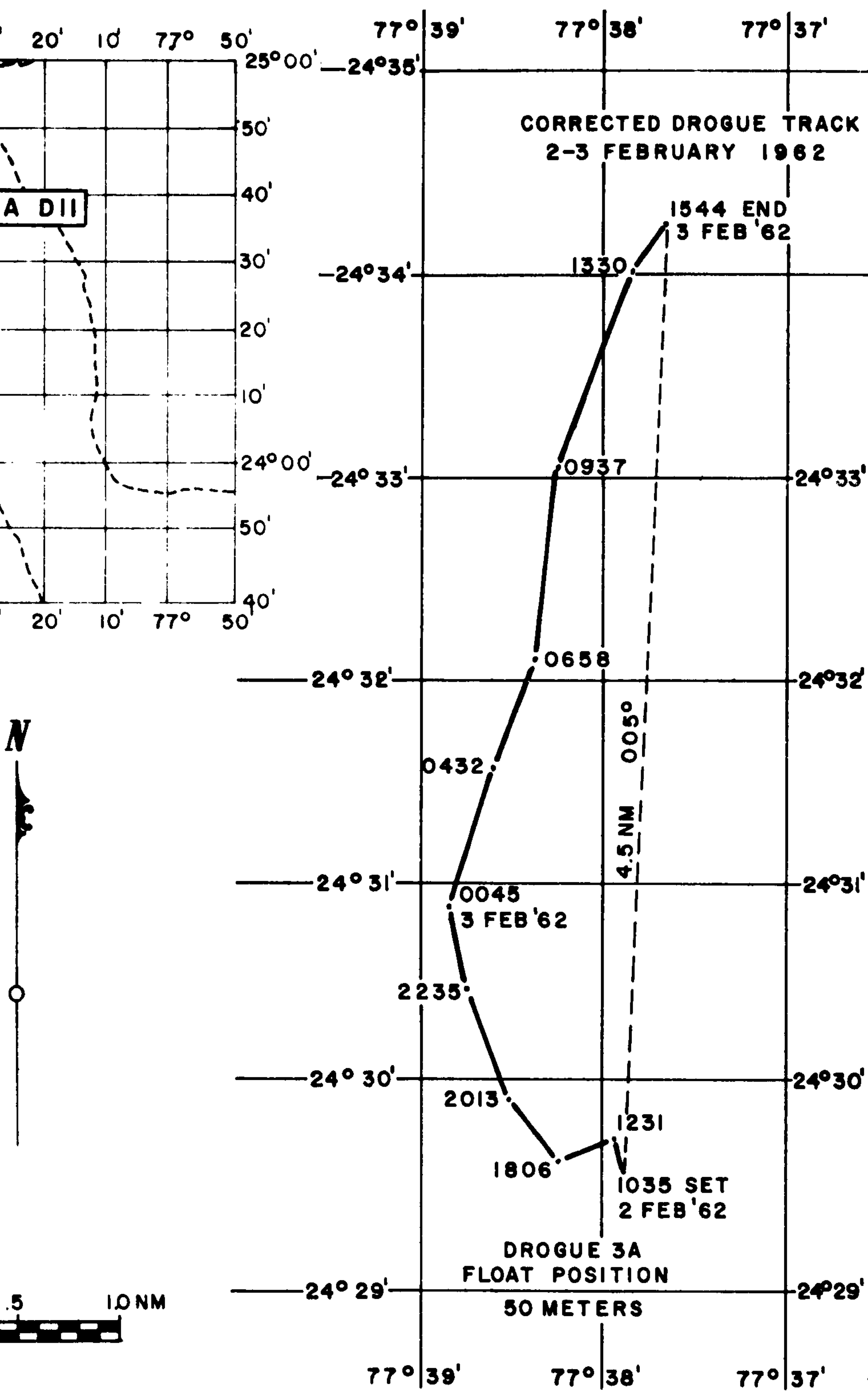


Figure A-23

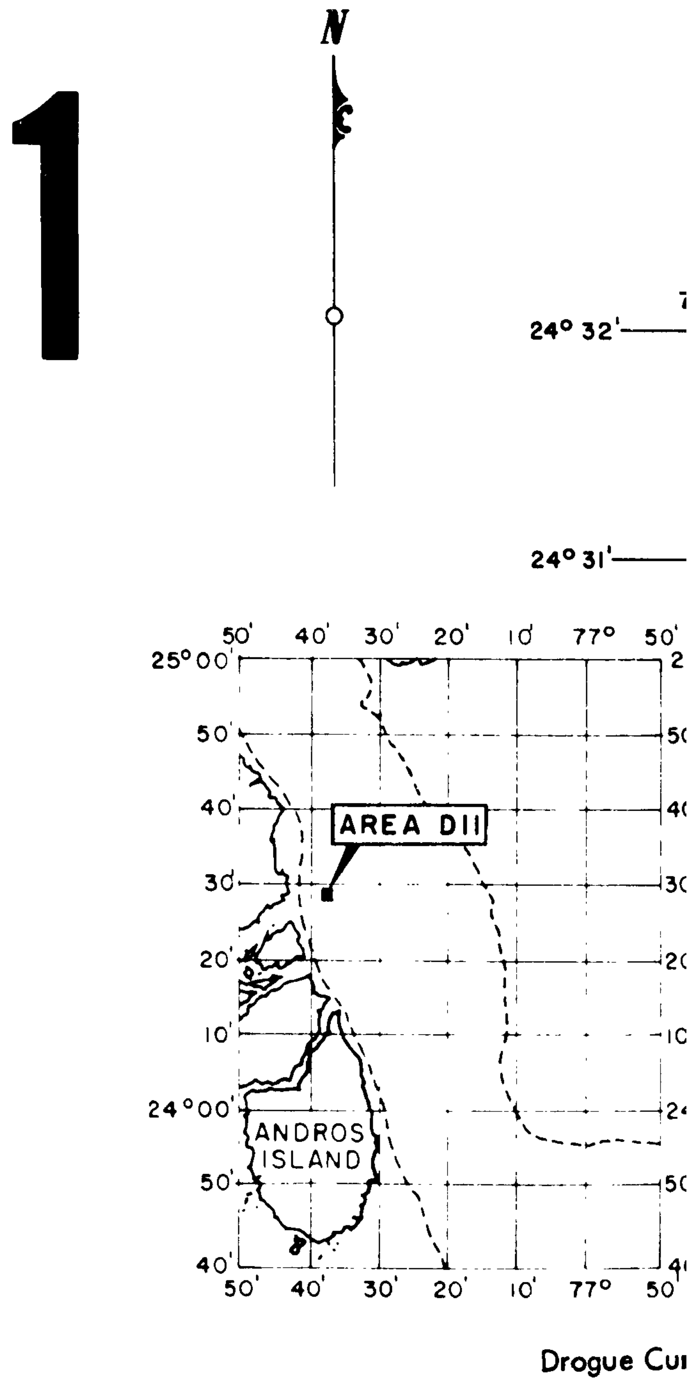


Time (Local)	Speed (cm/sec)	Direction (Degrees)
1055 - 1126	3.0	341
1126 - 1204	3.3	025
1204 - 1231	4.6	282
1231 - 1312	2.3	133
1312 - 1345	4.7	274
1345 - 1427	2.2	268
1427 - 1455	4.4	268
1455 - 1531	4.3	199
1531 - 1559	3.3	244
1559 - 1637	4.1	231
1637 - 1722	2.8	248
1722 - 1806	4.2	284
1806 - 1840	9.9	314
1840 - 2013	10.0	324
2013 - 2126	11.0	339
2126 - 2235	13.4	339
2235 - 2341	10.8	339
2341 - 0045	10.1	358
0045 - 0147	11.0	016
0147 - 0306	13.3	016
0306 - 0432	6.5	016
0432 - 0554	9.0	025
0554 - 0658	15.9	017
0658 - 0937	18.1	006
0937 - 1330	13.9	020
1330 - 1544	6.5	036
1055 - 1544	8.0	005

Average Speed: 7.8 cm/sec
Resultant: 4.5 NM in 28.8 hrs, 005°

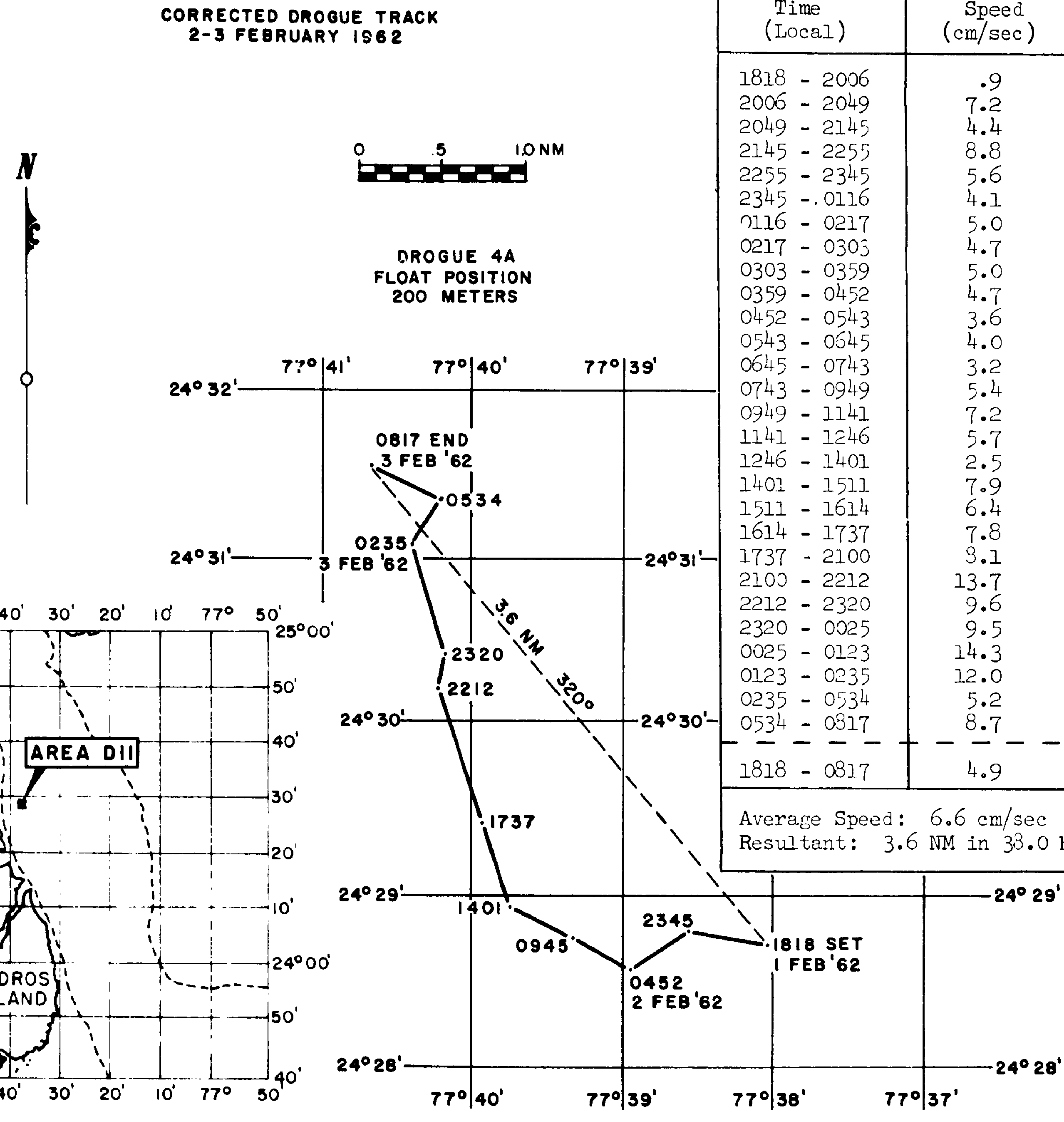
Drogue Current Observations - Area D11 - Depth 50 Meters - Drogue 3A

CORRECTED
2-3 FEBR



Drogue Cu

Figure A-24



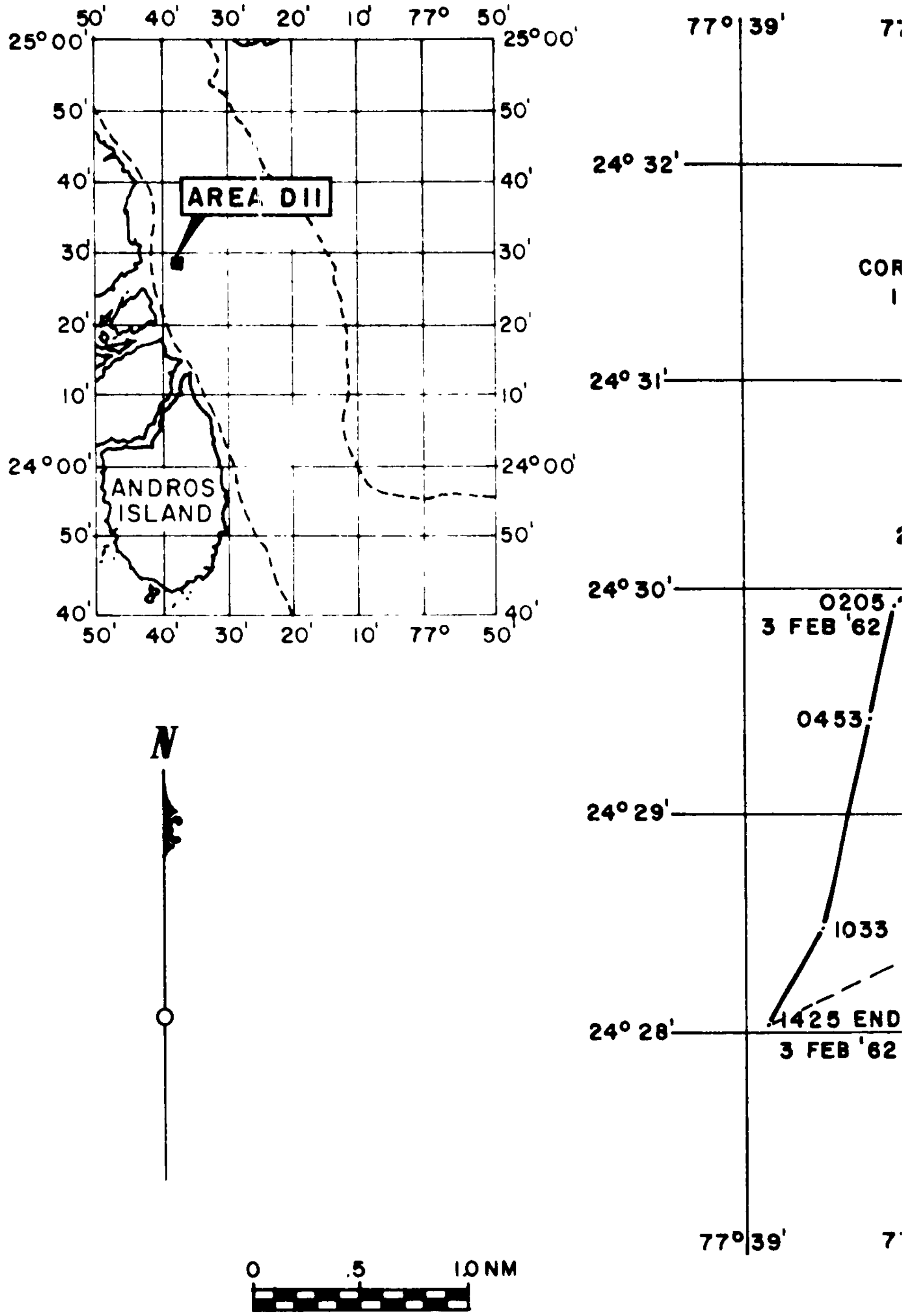
Time (Local)	Speed (cm/sec)	Direction (Degrees)
1818 - 2006	.9	291
2006 - 2049	7.2	277
2049 - 2145	4.4	263
2145 - 2255	8.8	287
2255 - 2345	5.6	288
2345 - 0116	4.1	242
0116 - 0217	5.0	214
0217 - 0303	4.7	256
0303 - 0359	5.0	215
0359 - 0452	4.7	262
0452 - 0543	3.6	262
0543 - 0645	4.0	301
0645 - 0743	3.2	301
0743 - 0949	5.4	304
0949 - 1141	7.2	298
1141 - 1246	5.7	315
1246 - 1401	2.5	254
1401 - 1511	7.9	242
1511 - 1614	6.4	328
1614 - 1737	7.8	347
1737 - 2100	8.1	345
2100 - 2212	13.7	334
2212 - 2320	9.6	012
2320 - 0025	9.5	342
0025 - 0123	14.3	336
0123 - 0235	12.0	354
0235 - 0534	5.2	034
0534 - 0817	8.7	291
1818 - 0817	4.9	320

Average Speed: 6.6 cm/sec
Resultant: 3.6 NM in 38.0 hrs, 320°

2

Drogue Current Observations - Area D11 - Depth 200 Meters - Drogue 4A

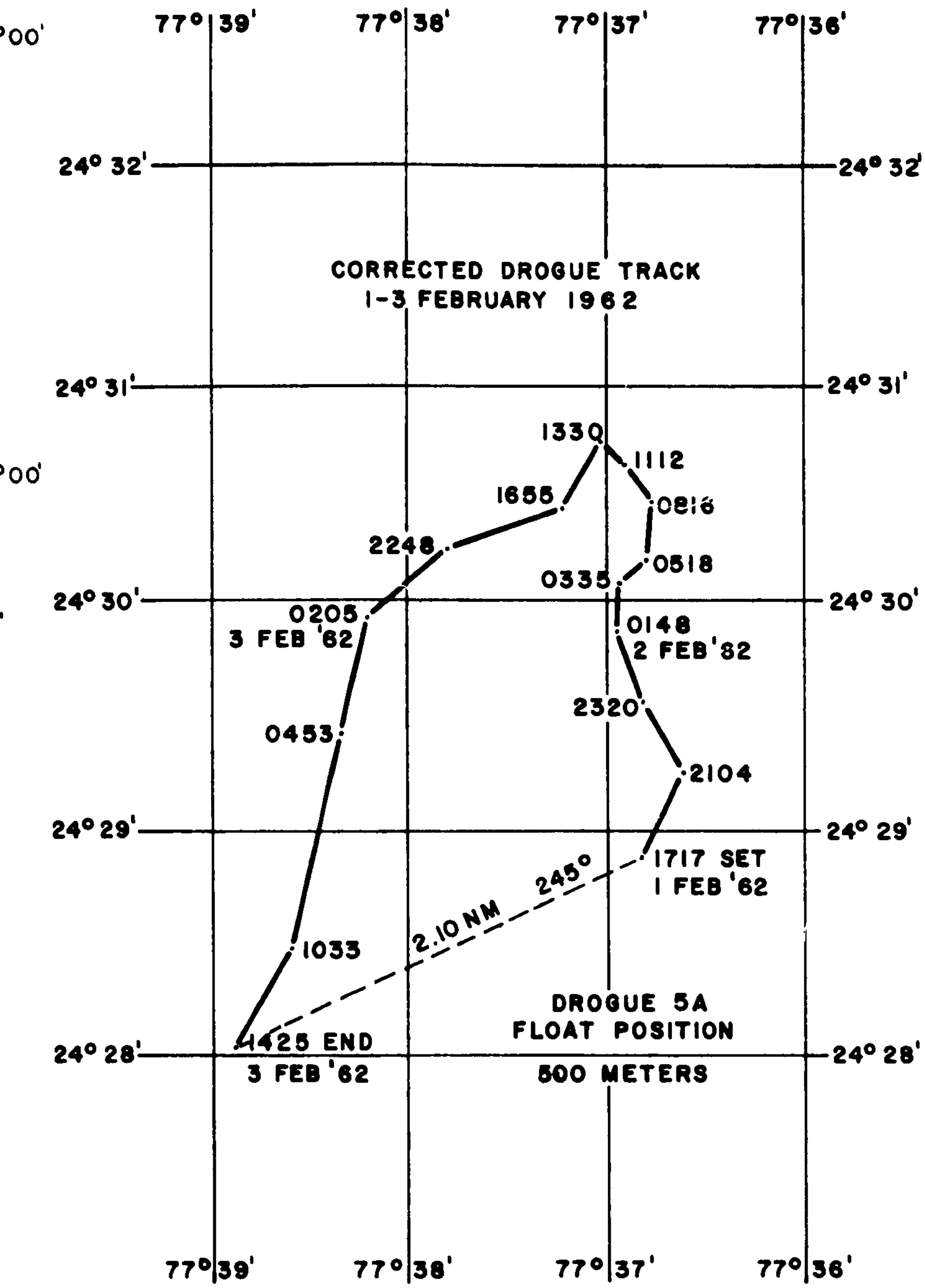
1



Drogue Current Observati

Figure A-25

2



Time (Local)	Speed (cm/sec)	Direction (Degrees)
1717 - 2017	6.0	032
2017 - 2104	7.3	348
2104 - 2200	10.0	333
2200 - 2320	6.6	327
2320 - 0050	7.9	338
0050 - 0148	6.9	344
0148 - 0243	5.0	345
0243 - 0335	8.3	011
0335 - 0428	6.4	055
0428 - 0518	3.1	046
0518 - 0615	6.0	359
0615 - 0716	4.5	014
0716 - 0816	3.6	004
0816 - 1015	4.4	321
1015 - 1112	3.3	330
1112 - 1218	4.2	321
1218 - 1330	3.0	289
1330 - 1442	3.9	219
1442 - 1548	5.6	201
1548 - 1655	6.0	201
1655 - 1829	5.9	227
1829 - 2030	6.1	251
2030 - 2120	6.2	263
2120 - 2248	4.6	266
2248 - 2353	6.2	248
2353 - 0058	7.2	224
0058 - 0205	7.8	232
0205 - 0459	10.5	193
0459 - 0732	11.7	188
0732 - 1033	7.2	199
1033 - 1204	6.4	230
1204 - 1425	7.7	199
1717 - 1425	2.4	245

Average Speed: 6.2 cm/sec
Resultant: 2.10 NM in 45.1 hrs, 245°

Drogue Current Observations - Area D11 - Depth 500 Meters - Drogue 5A

1

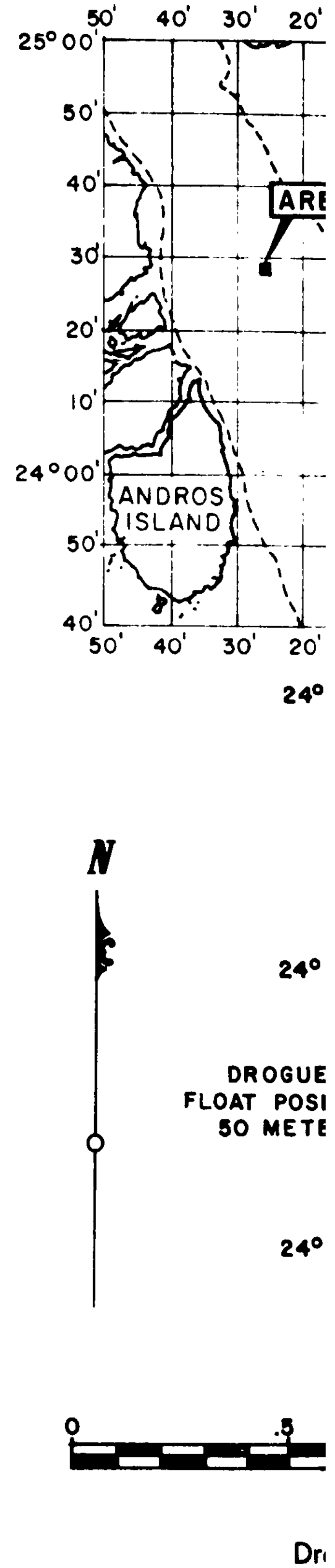
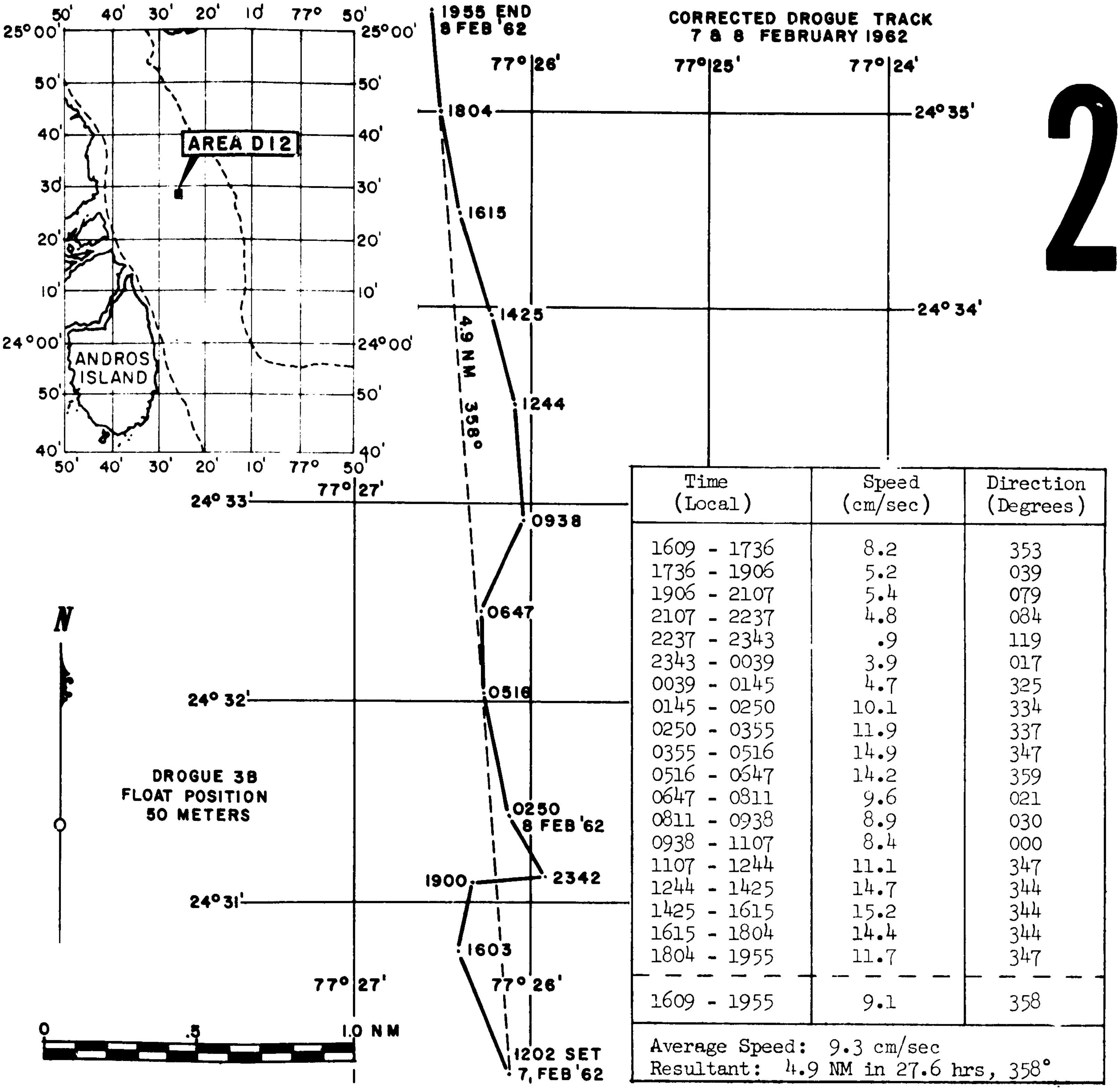


Figure A-26



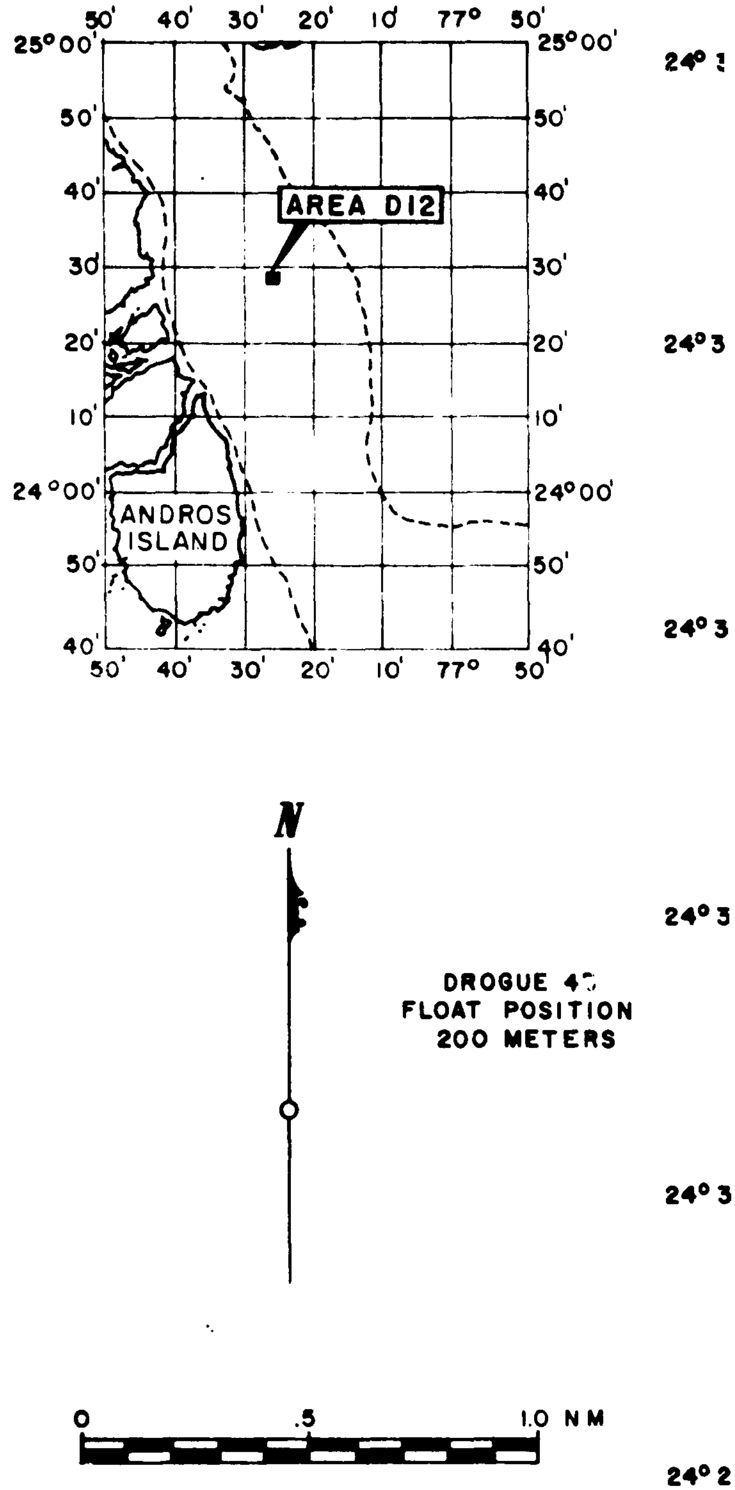
Time (Local)	Speed (cm/sec)	Direction (Degrees)
1609 - 1736	8.2	353
1736 - 1906	5.2	039
1906 - 2107	5.4	079
2107 - 2237	4.8	084
2237 - 2343	.9	119
2343 - 0039	3.9	017
0039 - 0145	4.7	325
0145 - 0250	10.1	334
0250 - 0355	11.9	337
0355 - 0516	14.9	347
0516 - 0647	14.2	359
0647 - 0811	9.6	021
0811 - 0938	8.9	030
0938 - 1107	8.4	000
1107 - 1244	11.1	347
1244 - 1425	14.7	344
1425 - 1615	15.2	344
1615 - 1804	14.4	344
1804 - 1955	11.7	347
1609 - 1955	9.1	358

Average Speed: 9.3 cm/sec
Resultant: 4.9 NM in 27.6 hrs, 358°

Drogue Current Observations - Area D12 - Depth 50 Meters - Drogue 3B

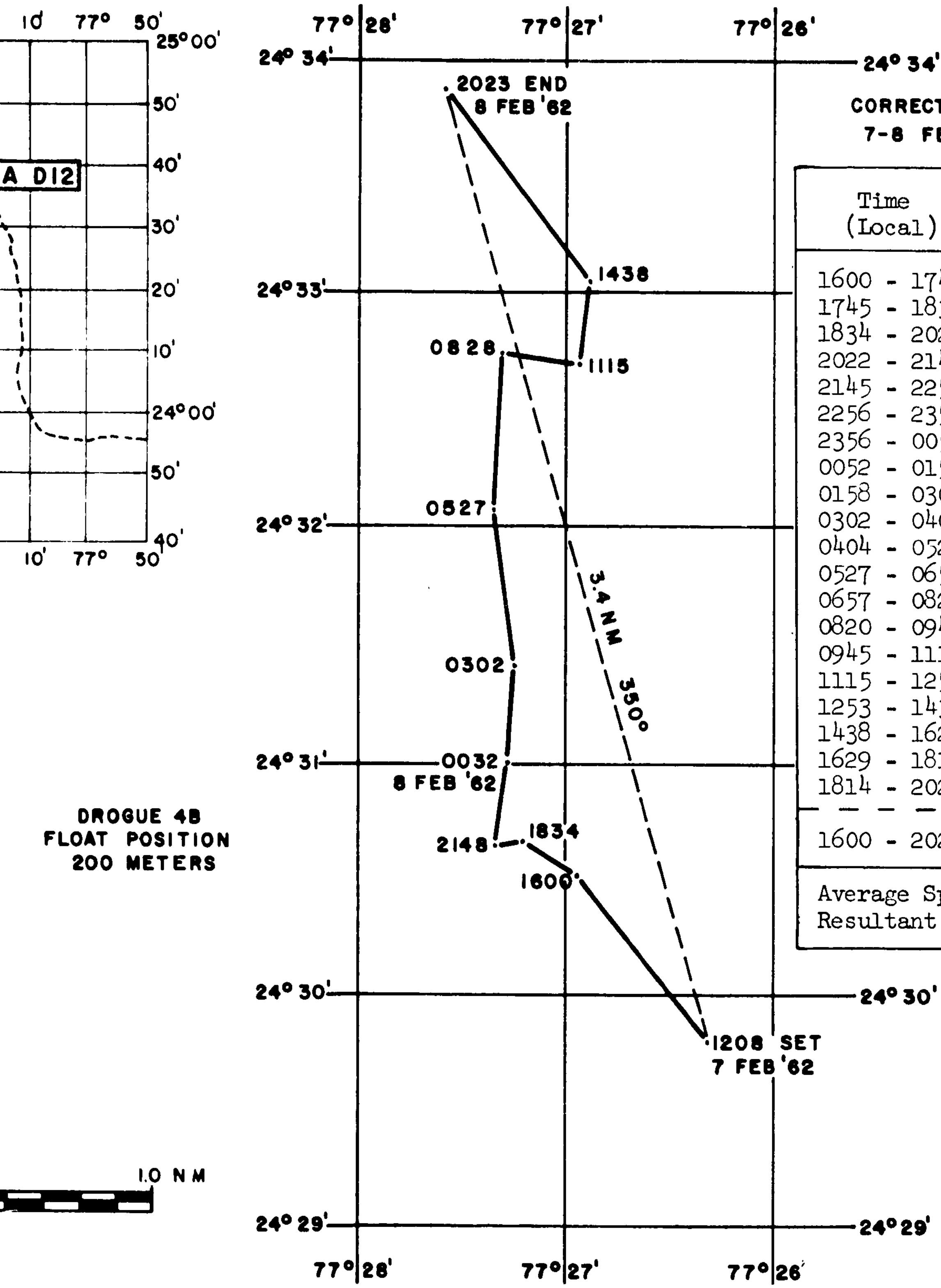
Figure A-26

1



Drogue Current C

Figure A-27



CORRECTED DROGUE TRACK
7-8 FEBRUARY 1962

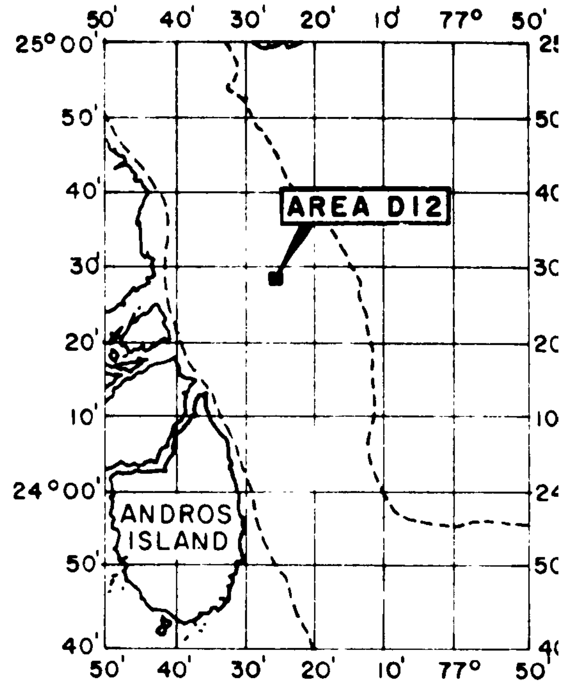
Time (Local)	Speed (cm/sec)	Direction (Degrees)
1600 - 1745	6.8	311
1745 - 1834	3.8	278
1834 - 2022	2.3	214
2022 - 2145	2.6	300
2145 - 2256	6.1	014
2256 - 2356	4.1	020
2356 - 0052	7.2	005
0052 - 0158	10.3	359
0158 - 0302	10.6	003
0302 - 0404	14.5	358
0404 - 0527	14.9	349
0527 - 0657	14.1	353
0657 - 0820	9.3	015
0820 - 0945	7.3	102
0945 - 1115	5.2	086
1115 - 1253	5.7	019
1253 - 1438	6.2	355
1438 - 1629	8.1	323
1629 - 1814	8.8	321
1814 - 2023	10.0	320
1600 - 2023	6.2	350

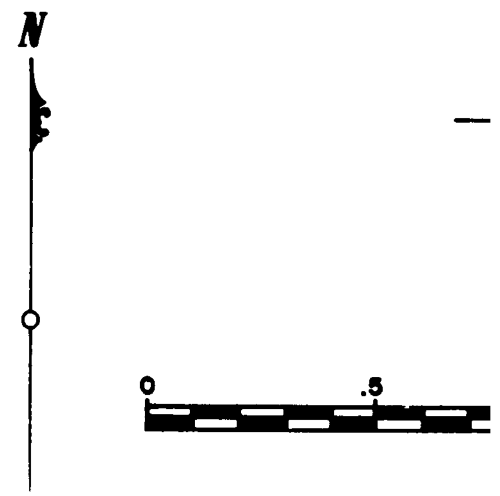
Average Speed: 8.1 cm/sec
Resultant: 3.4 NM in 28.4 hrs, 350°

2

Drogue Current Observations - Area D12 - Depth 200 Meters - Drogue 4B

1

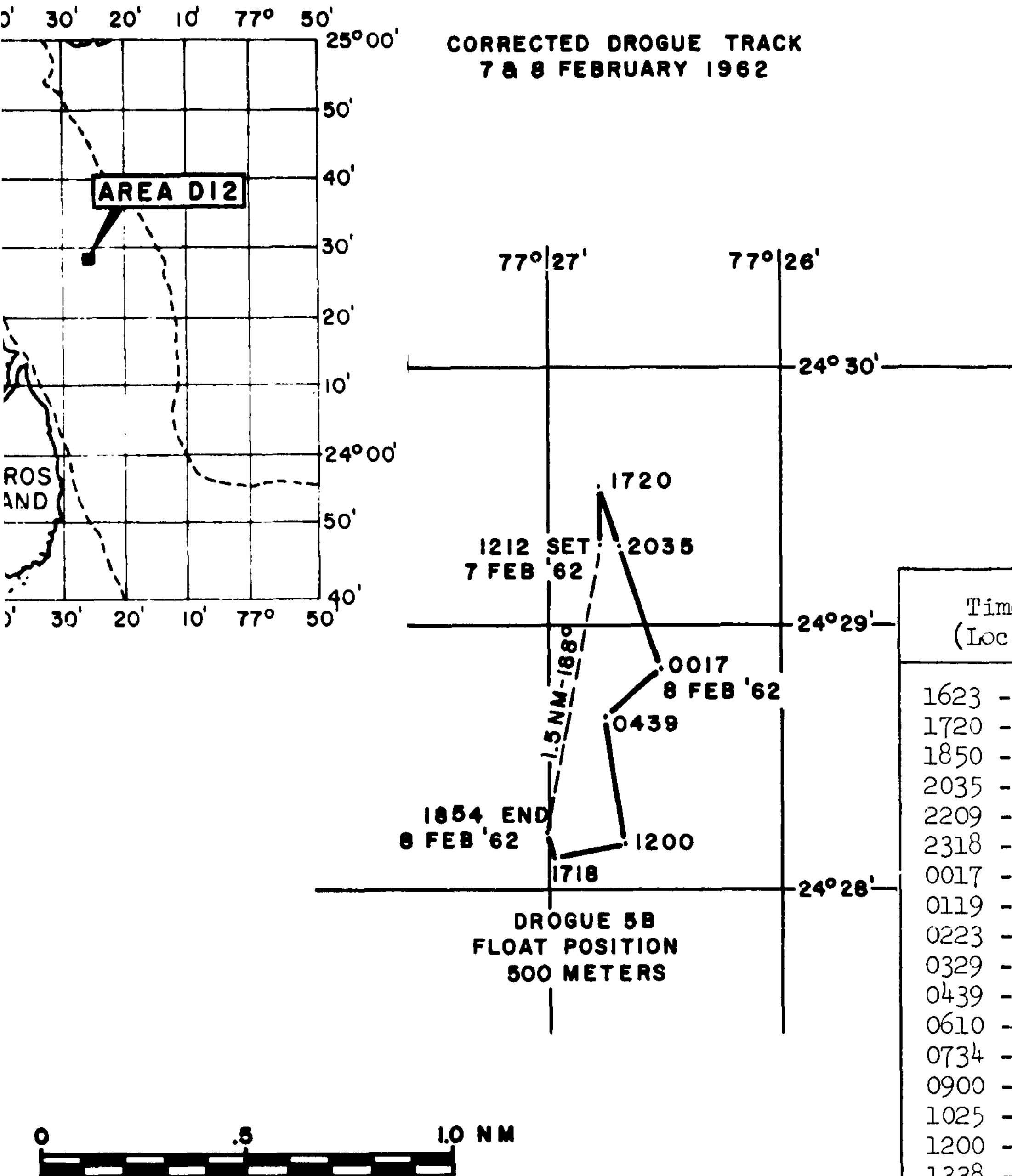




Drogue Cu

Figure A-28

2



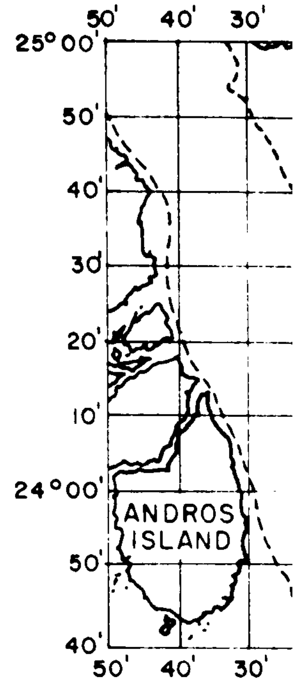
Time (Local)	Speed (cm/sec)	Direction (Degrees)
1623 - 1720	1.1	029
1720 - 1850	3.4	178
1850 - 2035	5.3	155
2035 - 2209	8.9	160
2209 - 2318	6.7	168
2318 - 0017	5.3	164
0017 - 0119	4.5	212
0119 - 0223	4.8	222
0223 - 0329	2.8	242
0329 - 0439	2.2	266
0439 - 0610	2.7	146
0610 - 0734	2.2	164
0734 - 0900	3.6	171
0900 - 1025	5.4	168
1025 - 1200	3.9	183
1200 - 1338	2.5	218
1338 - 1537	2.9	287
1537 - 1718	4.0	260
1718 - 1854	2.9	332
1623 - 1854	2.9	188

Average Speed: 3.9 cm/sec
Resultant: 1.5 NM in 26.5 hrs, 188°

Drogue Current Observations - Area D12 - Depth 500 Meters - Drogue 5B

8

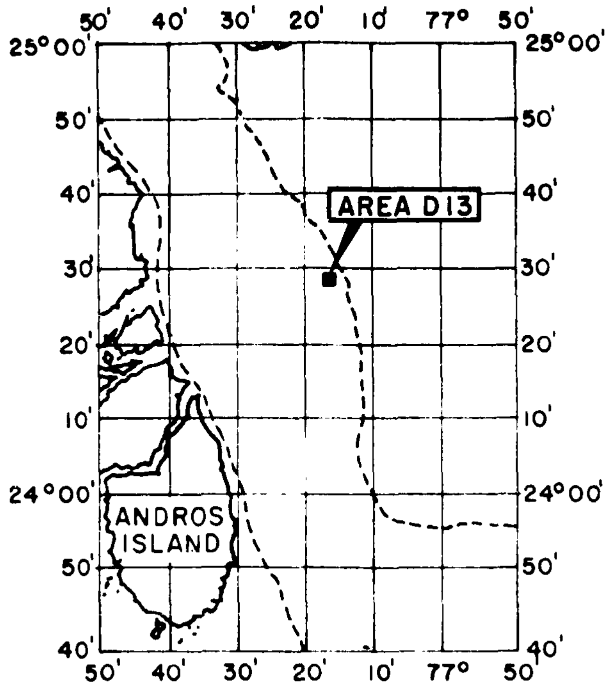
1

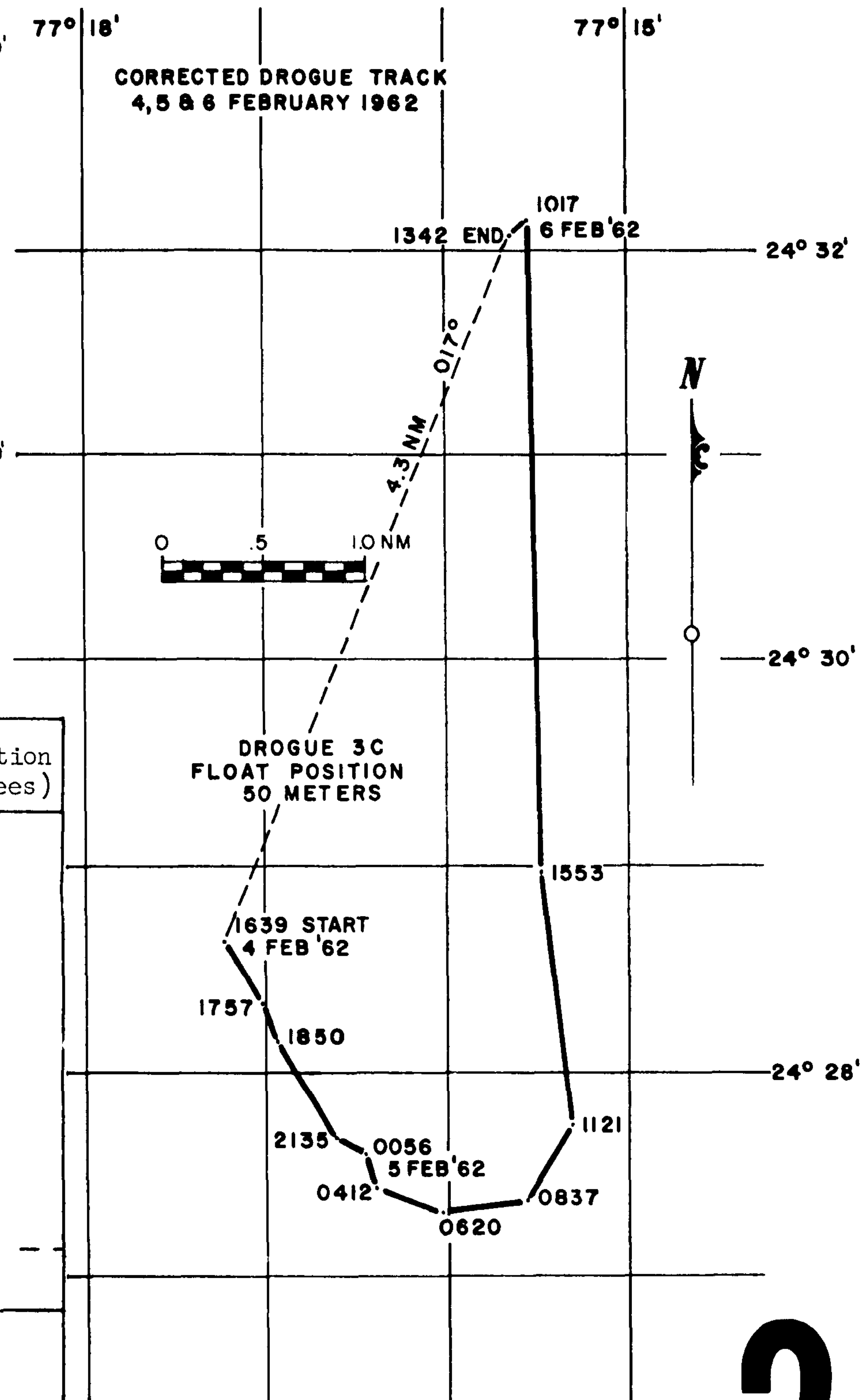


Time (Local)
1757 - 1850
1850 - 2055
2055 - 2135
2135 - 2250
2250 - 2349
2349 - 0056
0056 - 0228
0228 - 0412
0412 - 0620
0620 - 0837
0837 - 1121
1121 - 1553
1553 - 1017
1017 - 1242
1757 - 1242

Average Speed:
Resultant: 4.3 I

Figure A-29





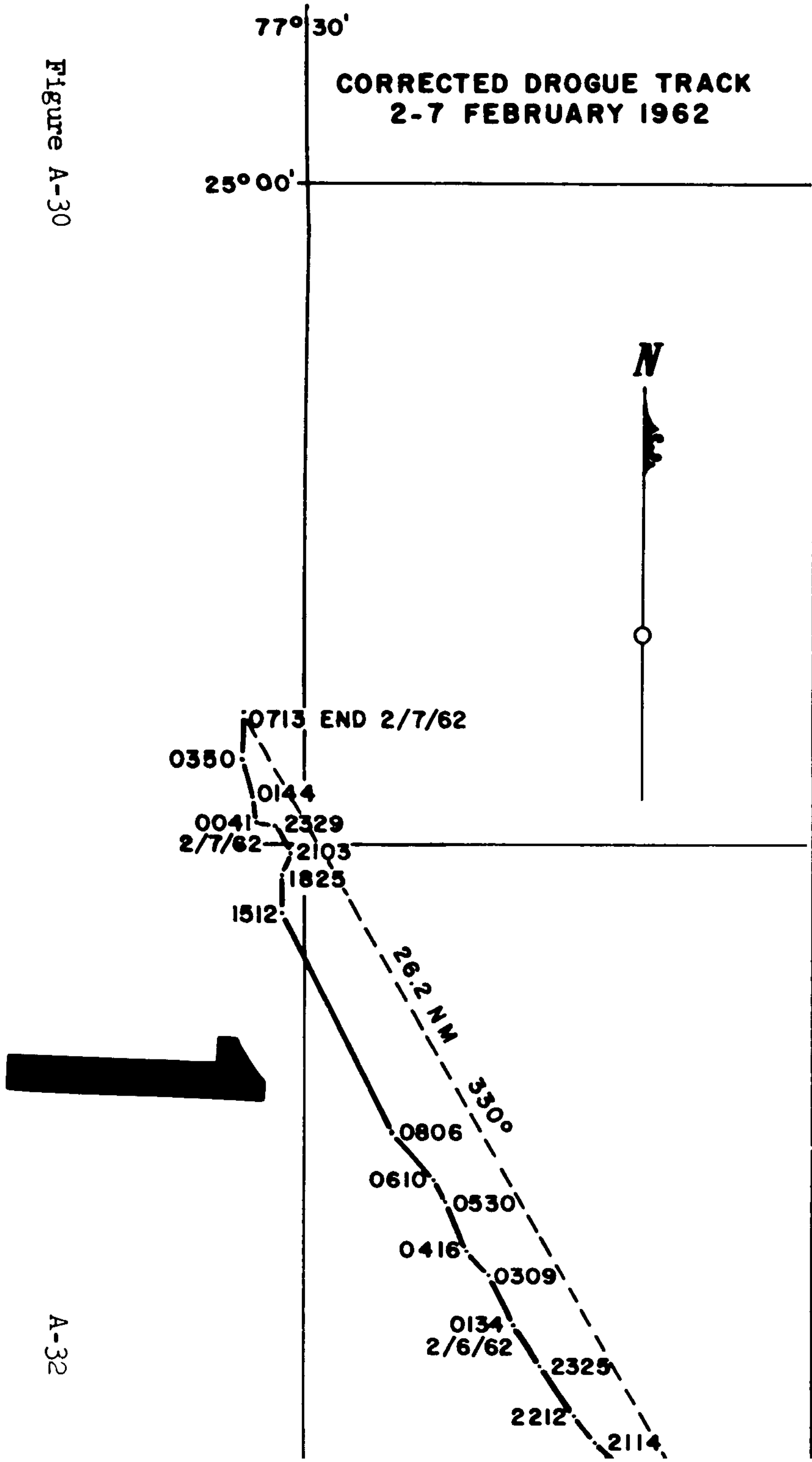
Time (Local)	Speed (cm/sec)	Direction (Degrees)
1757 - 1850	14.6	134
1850 - 2055	9.7	157
2055 - 2135	8.5	148
2135 - 2250	4.5	131
2250 - 2349	1.6	105
2349 - 0056	2.3	096
0056 - 0228	2.4	129
0228 - 0412	4.2	159
0412 - 0620	7.3	111
0620 - 0837	8.C	090
0837 - 1121	9.8	033
1121 - 1553	14.0	352
1553 - 1017	8.9	359
1017 - 1242	2.8	200
1757 - 1242	5.2	017

Average Speed: 7.6 cm/sec
Resultant: 4.3 NM in 42.8 hrs, 017°

Drogue Current Observations - Area D13 - Depth 50 Meters - Drogue 3C

2

Figure A-29

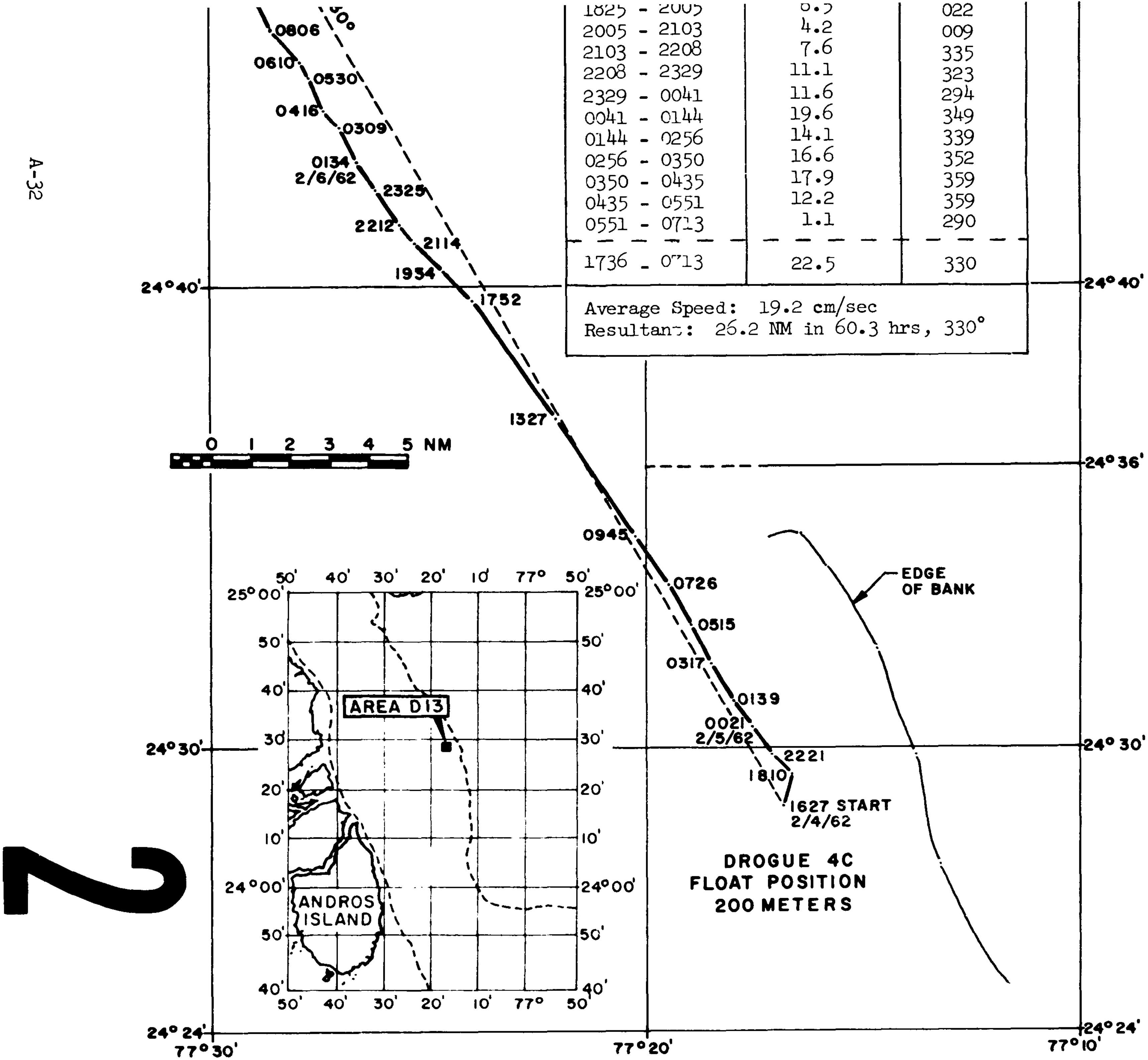


Time (Local)	Speed (cm/sec)	Direction (Degrees)
1736 - 1910	8.5	025
1910 - 1954	5.6	293
1954 - 2111	7.2	311
2111 - 2221	15.0	321
2221 - 2320	15.8	330
2320 - 0021	20.4	327
0021 - 0139	29.3	325
0139 - 0317	28.8	330
0317 - 0515	25.4	334
0515 - 0726	22.2	329
0726 - 0945	28.4	327
0945 - 1327	41.9	326
1327 - 1752	36.4	326
1752 - 1934	25.8	316
1934 - 2114	27.1	316
2114 - 2212	27.1	318
2212 - 2355	27.2	328
2355 - 0127	23.6	326
0127 - 0134	17.4	294
0134 - 0309	28.0	335
0309 - 0416	20.2	313
0416 - 0530	34.7	339
0530 - 0610	29.2	321
0610 - 0806	26.1	324
0806 - 1512	25.8	331
1512 - 1626	16.3	007
1626 - 1723	6.0	352
1723 - 1825	6.0	352
1825 - 2005	6.5	022
2005 - 2103	4.2	009
2103 - 2208	7.6	335
2208 - 2329	11.1	323
2329 - 0041	11.6	294
0041 - 0144	19.6	349
0144 - 0256	14.1	339
0256 - 0350	16.6	352
0350 - 0435	17.9	359
0435 - 0551	12.2	359
0551 - 0713	1.1	290

Figure A-30

1825 - 2005	[illegible]	022
2005 - 2103	4.2	009
2103 - 2208	7.6	335
2208 - 2329	11.1	323
2329 - 0041	11.6	294
0041 - 0144	19.6	349
0144 - 0256	14.1	339
0256 - 0350	16.6	352
0350 - 0435	17.9	359
0435 - 0551	12.2	359
0551 - 0713	1.1	290
1736 - 0713	22.5	330

Average Speed: 19.2 cm/sec
Resultant: 26.2 NM in 60.3 hrs, 330°



Drogue Current Observations - Area D13 - Depth 200 Meters - Drogue 4C

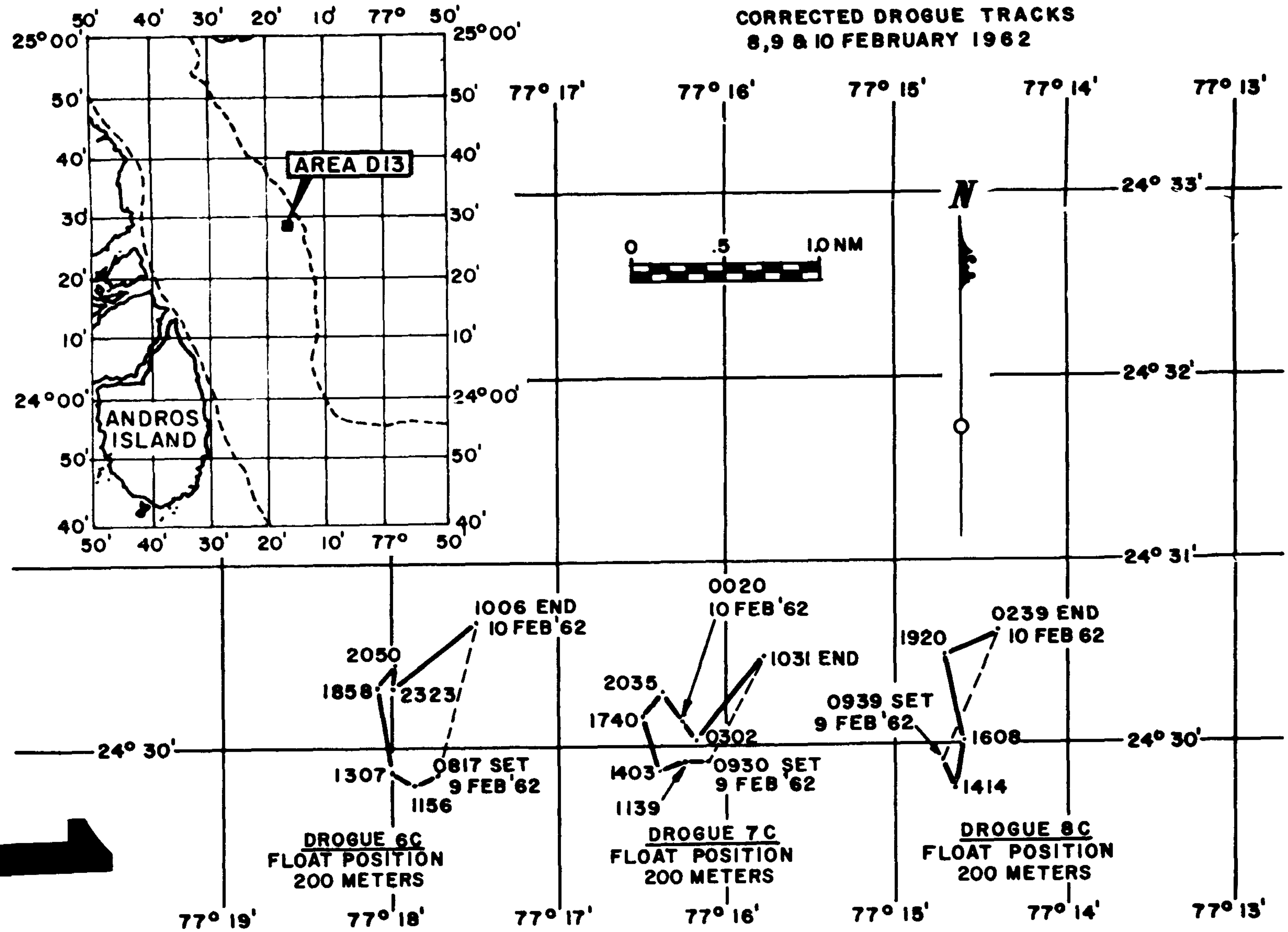


Figure A-31

DROGUE 6C DATA

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1156 - 1307	6.1	282
1307 - 1351	5.6	346
1351 - 1639	2.4	342
1639 - 1753	7.1	003
1753 - 1853	7.2	006
1853 - 1950	4.9	033
1950 - 2050	3.6	048

DROGUE 7C DATA

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1139 - 1248	3.1	235
1248 - 1403	6.2	258
1403 - 1625	2.8	231
1625 - 1740	8.7	006
1740 - 1838	5.8	018
1838 - 1935	1.6	040
1935 - 2035	3.1	081

DROGUE 6C DATA

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1156 - 1307	6.1	282
1307 - 1351	5.6	346
1351 - 1639	2.4	342
1639 - 1753	7.1	003
1753 - 1853	7.2	006
1853 - 1950	4.9	033
1950 - 2050	3.6	048
2050 - 2208	3.6	227
2208 - 2323	2.5	168
2323 - 0203	.4	051
0203 - 0324	1.9	312
0324 - 1006	4.4	058
1156 - 1006	2.8	020

Average Speed: 4.1 cm/sec
Resultant: 0.9 NM in 22.2 hrs, 020°

DROGUE 7C DATA

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1139 - 1248	3.1	235
1248 - 1403	6.2	258
1403 - 1625	2.8	231
1625 - 1740	8.7	006
1740 - 1838	5.8	018
1838 - 1935	1.6	040
1935 - 2035	3.1	081
2035 - 2140	3.8	114
2140 - 2305	2.9	157
2305 - 0020	4.1	187
0020 - 0144	3.3	145
0144 - 0302	1.2	093
0302 - 1031	4.3	038
1139 - 1031	1.6	035

Average Speed: 3.8 cm/sec
Resultant: 0.7 NM in 22.9 hrs, 035°

2

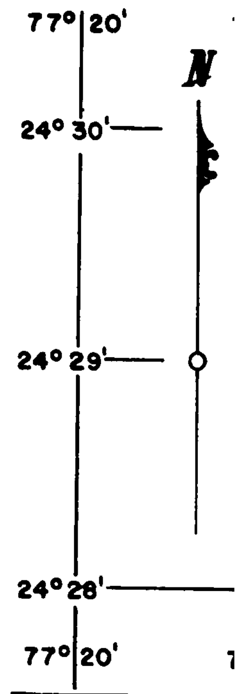
DROGUE 8C DATA

Time (Local)	Speed (cm/sec)	Direction (Degrees)
1230 - 1414	.9	255
1414 - 1609	7.8	011
1609 - 1725	9.3	356
1725 - 1822	10.9	349
1822 - 1920	3.7	001
1920 - 2019	1.6	001
2019 - 2121	4.5	050
2121 - 2245	2.9	075
2245 - 2400	3.3	113
2400 - 0119	2.3	048
0119 - 0239	.4	310
1230 - 0239	3.3	015

Average Speed: 4.3 cm/sec
Resultant: 0.9 NM in 14.2 hrs, 015°

Drogue Current Observations - Area D13 - Depth 200 Meters - Drogues 6C, 7C, and 8C

CORRECTI
4,5 & 6

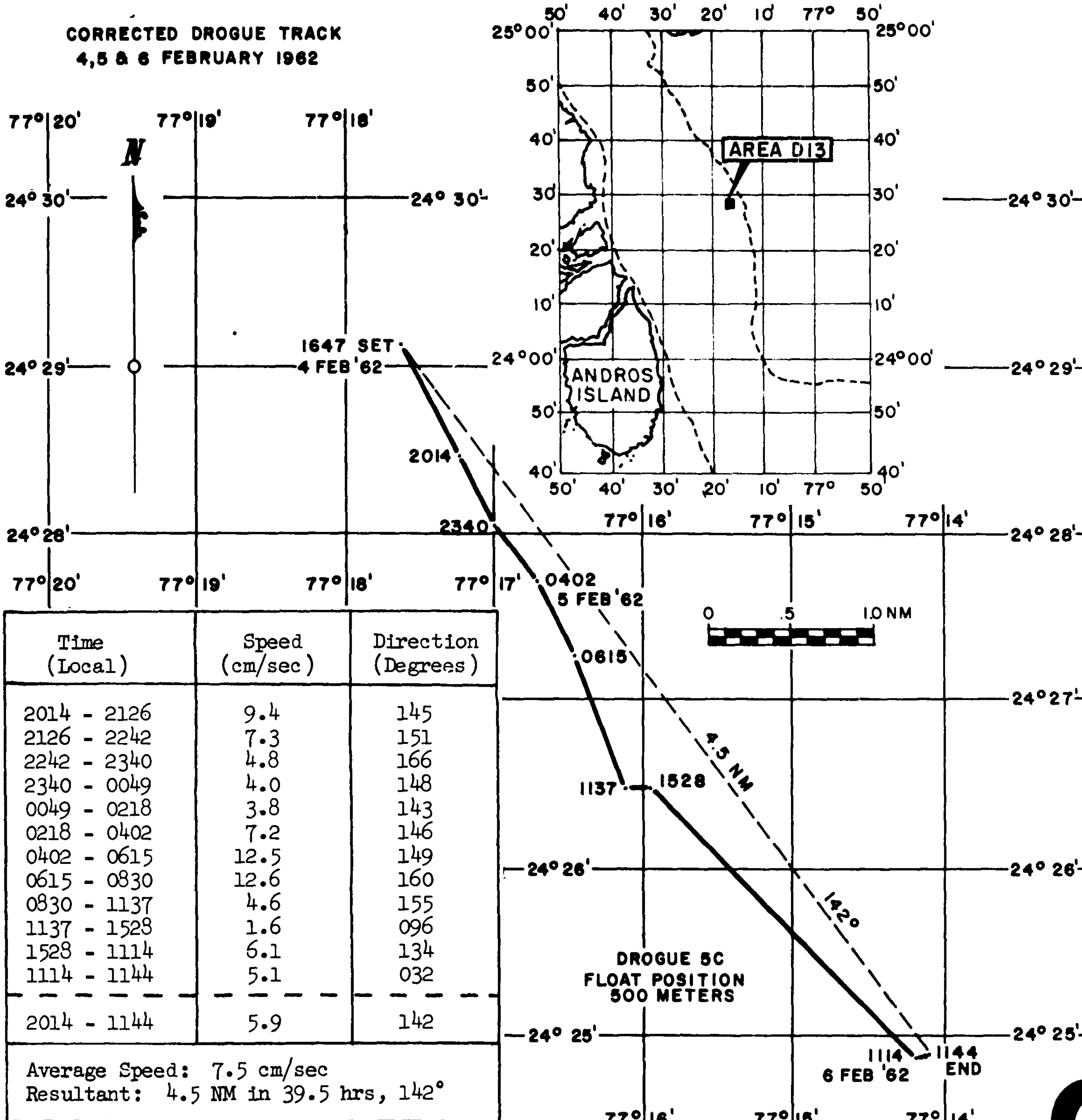


Time (Local)
2014 - 2126
2126 - 2242
2242 - 2340
2340 - 0049
0049 - 0218
0218 - 0402
0402 - 0615
0615 - 0830
0830 - 1137
1137 - 1528
1528 - 1114
1114 - 1144
2014 - 1144

Average Speec
Resultant: l

1

Figure A-32

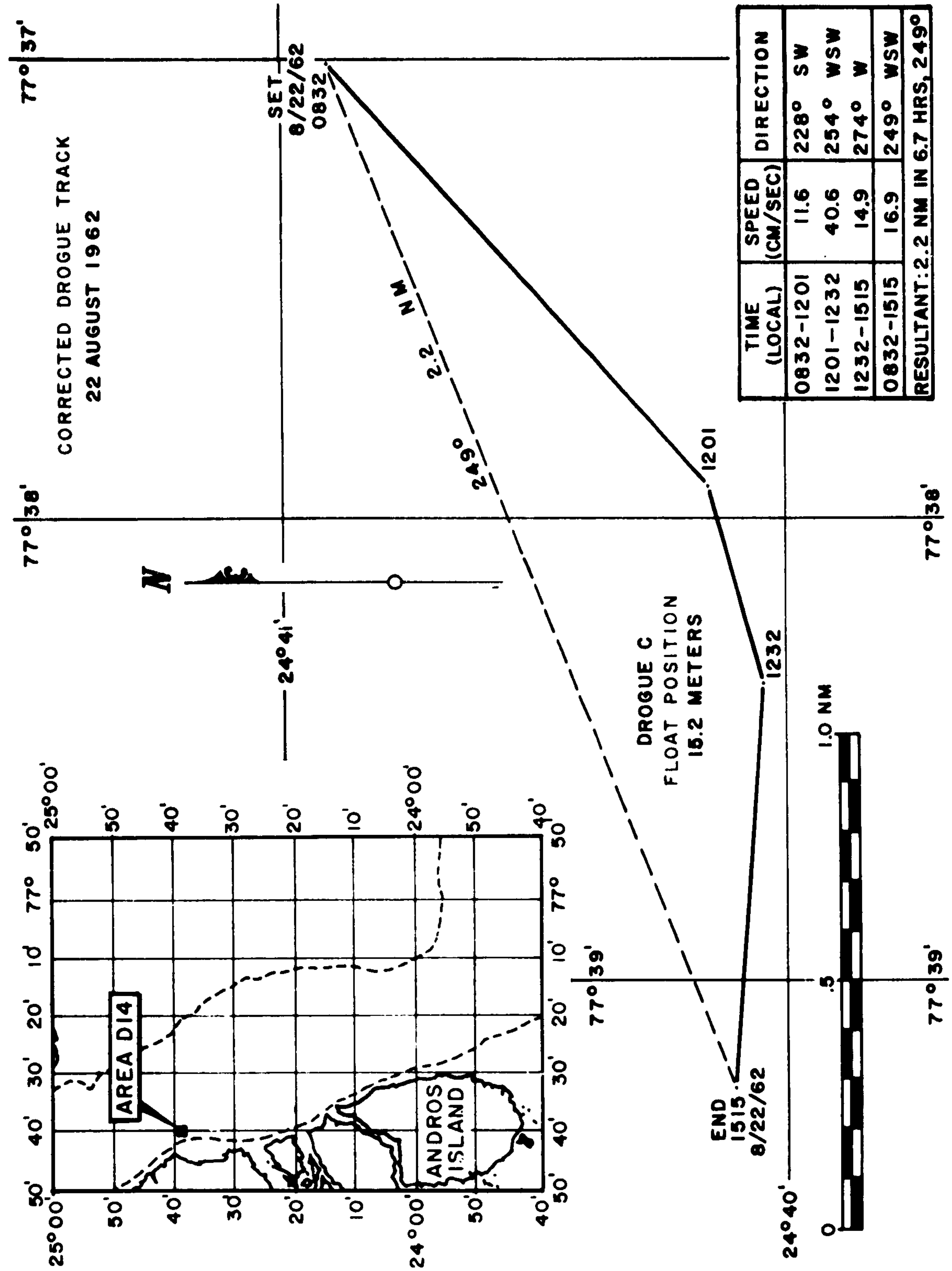


Time (Local)	Speed (cm/sec)	Direction (Degrees)
2014 - 2126	9.4	145
2126 - 2242	7.3	151
2242 - 2340	4.8	166
2340 - 0049	4.0	148
0049 - 0218	3.8	143
0218 - 0402	7.2	146
0402 - 0615	12.5	149
0615 - 0830	12.6	160
0830 - 1137	4.6	155
1137 - 1528	1.6	096
1528 - 1114	6.1	134
1114 - 1144	5.1	032
2014 - 1144	5.9	142

Average Speed: 7.5 cm/sec
Resultant: 4.5 NM in 39.5 hrs, 142°

Drogue Current Observations - Area D13 - Depth 500 Meters - Drogue 5C

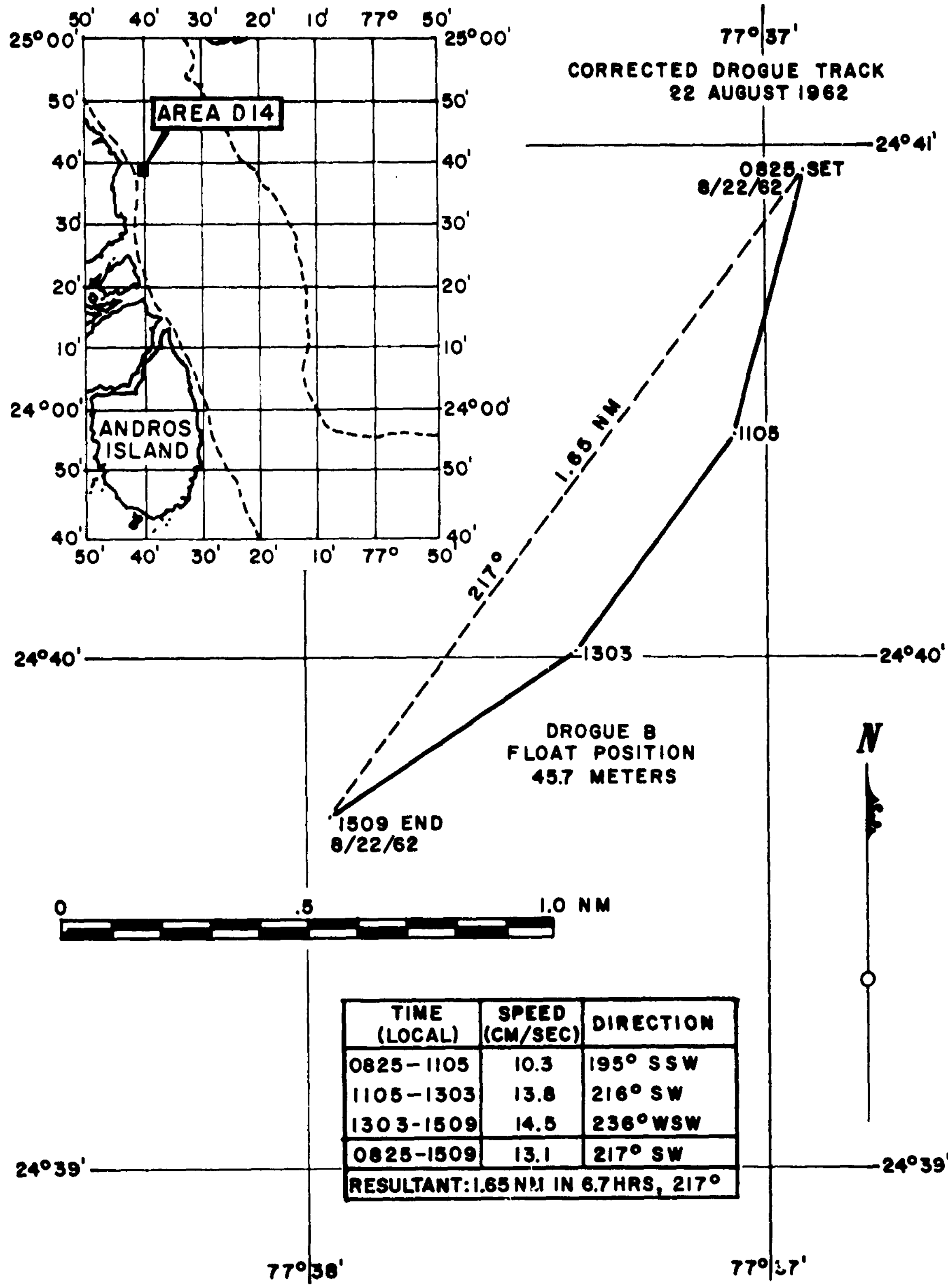
Figure A-32



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0832-1201	11.6	228° SW
1201-1232	40.6	254° WSW
1232-1515	14.9	274° W
0832-1515	16.9	249° WSW
RESULTANT: 2.2 NM IN 6.7 HRS, 249°		

Drogue Current Observations - Area D14 - Depth 15.2 Meters

Figure A-33



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0825–1105	10.3	195° SSW
1105–1303	13.8	216° SW
1303-1509	14.5	236° WSW
0825-1509	13.1	217° SW
RESULTANT: 1.65 NM IN 6.7 HRS, 217°		

Drogue Current Observations - Area D14 - Depth 45.7 Meters

1

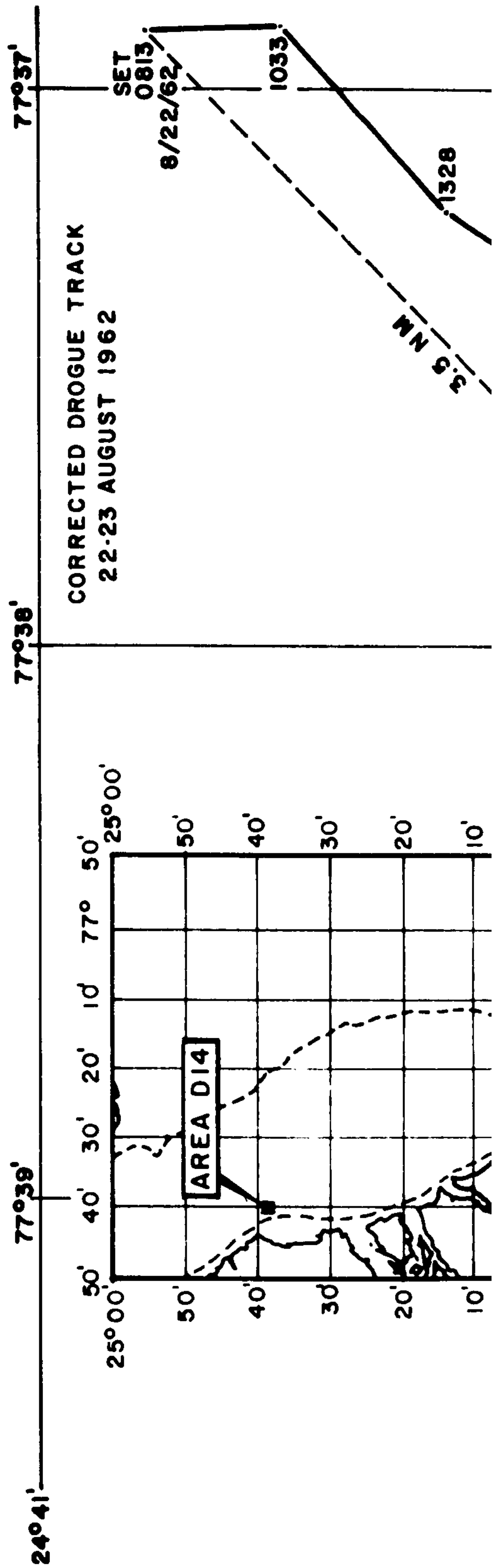
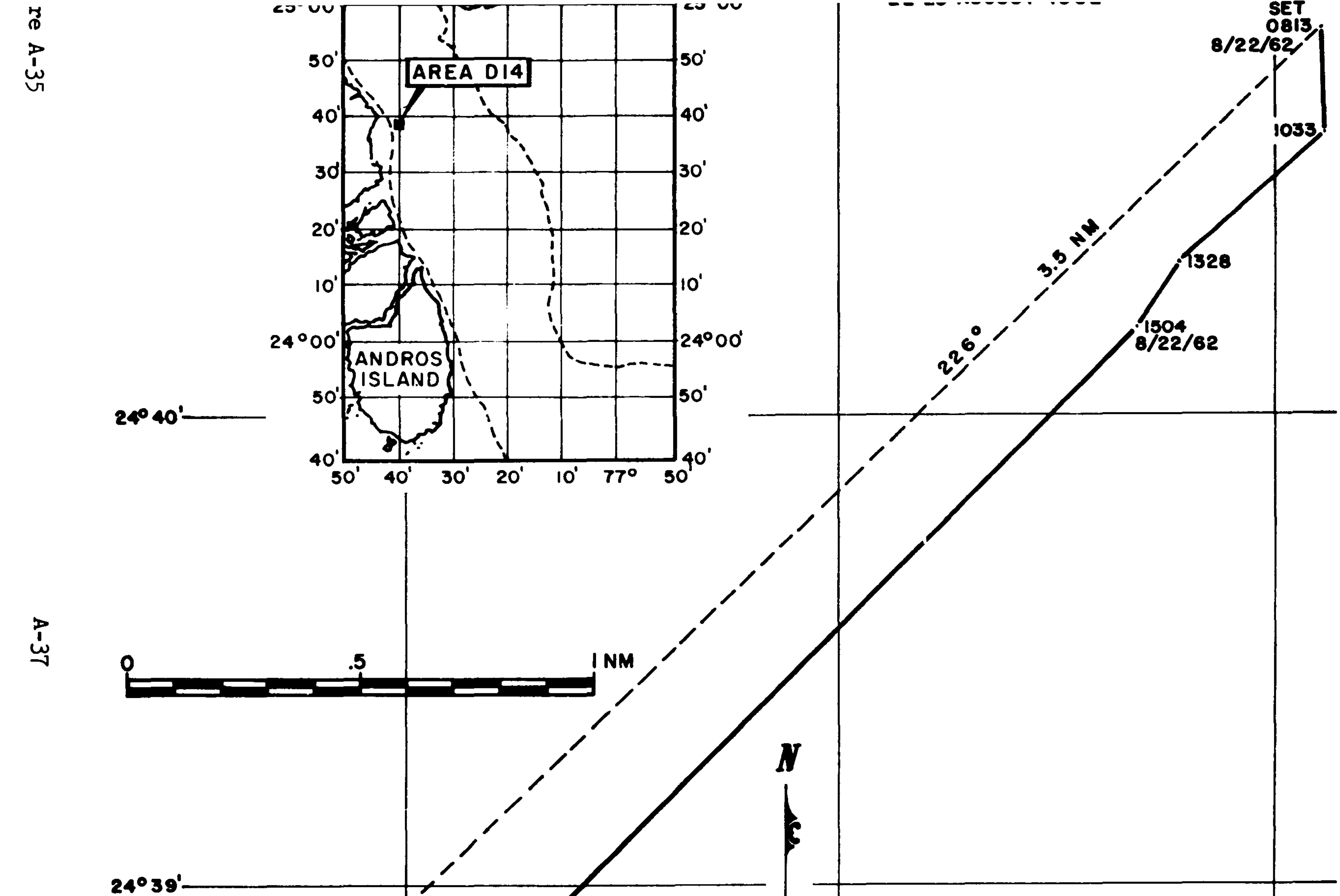

CORRECTED DROGUE TRACK
22-23 AUGUST 1962
SET
0813
8/22/62
1033
1328
3.5 NM
77°37'
77°38'
77°39'
24°41'
AREA D14
25°00'
50'
40'
30'
20'
10'
77°

Figure A-35



TIME (LOCAL)	SPEED (CM/SEC)	DIRECTION
0813-1033	2.9	178° S
1033-1328	7.2	228° SW
1328-1504	5.7	213° SW
1504-0719	6.2	225° SW
0719-0841	4.5	255° WSW
0841-1014	6.2	218° SW
1014-1356	5.0	254° WSW
1356-1505	4.9	273° W
0813-1505	4.5	226° SW
RESULTANT: 3.5 NM IN 30.9 HRS, 226°		

Drogue Current Observations - Area D14 - Depth 457.3 Meters

re A-35

APPENDIX B

A summary of the water current data taken in TOTO with Ekman current meters.

Table B-1. Summary of Water Current Data - Area E1 TOTO August 1958

Ship moor - single point Date - 21 August 1958		Location - 24°19.0'N 77°39.0'W Current meter - Ekman	
Time (EST)	Depth (meters)	Current Speed (cm/sec)	Direction (degrees)
0901	10	9.44	210
0935	↓	17.24	200
1036	↓	19.99	218
1105	↓	20.18	-
1136	↓	20.64	217
1213	↓	18.61	-
1238	↓	17.43	221
1335	↓	15.07	234
1407	↓	12.06	254
1435	↓	9.05	255
1505	↓	9.11	290
1540	↓	12.13	013
1604	↓	16.84	027

Table B-2. Summary of Water Current Data - Area E4 TOTO December 1961

Barge - anchored Date - 4 December 1961	Water depth - ~4 meters	Location - 24°20.0'N 77°41.0'W Current meter - Ekman	
Time (EST)	Depth (meters)	Current Speed (cm/sec)	Direction (degrees)
1335	~3	3	140
1404	↓	15	259
1500	↓	35	256
1623	↓	42	258 (assumed)
1655	↓	96	261
1837	↓	7	254
1903	↓	7	095
1935	↓	32	047
2016	↓	28	074

Table B-3. Summary of Water Current Data - Area E2 TOTO December 1961

Ship moor - three point Location - 24°25.0'N 77°30.0'W
Date - 6 December 1961 Current meter - Ekman

Time (EST)	Current Depth (meters)	Current Speed (cm/sec)	Current Direction (degrees)	Wind Speed (knots)	Wind Direction (degrees)
1340	25	7	192	-	-
1425	30	5	225	9	134
1515	30	3	248	11	134
1617	30	5	316	10	132
1715	305	4	000	9	129

Table B-4. Summary of Water Current Data - Area E3 TOTO December 1961

Ship moor - single point Location - 24°25.0'N 77°32.0'W
Date - 12-13 Dec 1961 Current meter - Ekman

Time (EST)	Current Depth (meters)	Current Speed (cm/sec)	Current Direction (degrees)	Wind (estimated) Speed (knots)	Wind (estimated) Direction (degrees)
2017	12	18	004	10	135
2132		13	180	12	
2212		19	167	14	
2300		19	166	14	
0010		30	162	16	
0035		23	154	16	
0115		22	161	18	
0205		27	346	18	
0235		22	155	18	
0310		51	149	20	
0340		66	132	20	
0420		35	138	20	
1950	30	21	326	10	135
2125	120	10	075	12	
2210	285	8	243	14	
2255	285	20?	295	14	
2340	285	No speed	280	16	
0030	274	3	No direction	20	

Table B-5. Summary of Water Current Data - Area E5 TOTO January 1962

Ship moor - single point   Location - 24°24.75'N 77°32.32'W
Date - 31 January 1962   Current meter - Ekman

Time (EST)	Depth (meters)	Current Speed (cm/sec)	Direction (degrees)
1221	10	10.6	348
1242	100	9.0	334
1308	400	2.8	057
1406	1000	1.1	247
1530	10	10.3	010
1622	100	5.5	316
1649	400	7.0	001
1803	1000	2.1	098
1916	10	8.3	035
1935	100	2.8	273
2007	400	0.8	105
2134	1000	<0.2	-

APPENDIX C

A summary of the water current data taken in TOTO with Roberts current meters.

Table C-1. Summary of Water Current and Wind Data - Area R1 TOTO March 1960

Ship moor - three point Date - 9-14 March 1960					Location - 24°35'N 77°34'W Current meter - Roberts		
	Current				Wind		
Date	Time (EST)	Depth (meters)	Speed (knots)	Direction (degrees)	Time (EST)	Speed (knots)	Direction (degrees)
3/9/60	0940	10	0.7	033	0900	15	070
	0945	25	0.6	303	0915	15	070
	0948	50	0.4	287	0930	15	070
	0952	75	0.3	306	0945	15	070
	0959	100	0.1	257	1000	14	070
	1002	150	0.2	290			
	1007	200	0.35	288			
	1029	10	0.6	058	1015	14	070
	1033	25	0.6	315	1030	14	070
	1040	50	0.4	284	1045	15	070
	1055	75	0.3	295	1100	15	070
	1100	100	0.3	287	1115	15	070
	1108	150	0.3	289			
	1115	200	<0.2				
	1143	10	0.6	066	1130	15	070
	1147	25	0.5	311	1145	12	070
	1151	50	0.4	288	1200	12	070
	1158	75	0.3	293	1215	12	070
	1203	100	0.3	288			
	1208	150	0.2	291			
	1215	200	0.3	294			
	1237	10	0.6	058	1230	12	070
	1243	25	0.5	301	1245	13	100
	1248	50	0.45	288	1300	13	100
	1253	75	0.35	289	1315	13	100
	1258	100	0.3	290			
	1305	150	0.3	286			
	1310	200	0.3	294			
	1337	10	0.6	053	1330	13	100
	1345	25	0.4	325	1345	13	100
	1350	50	0.4	286	1400	11	100
	1357	75	0.3	294	1415	11	100
	1402	100	0.3	291			
	1410	150	0.3	294			
	1417	200	0.4	290			

Date	Current Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Wind Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/9/60	1447	10	0.6	056	1430	11	100
	1457	25	0.6	327	1445	11	100
	1501	50	0.4	337	1500	14	110
	1506	75	0.5	338	1515	14	110
	1510	100	0.2	343	1530	14	110
	1520	150	0.4	350			
	1526	200	0.4	359			
	1545	10	0.6	059	1545	14	110
	1600	25	0.5	337	1600	14	120
	1605	50	0.3	319	1615	14	120
	1610	75	0.4	306	1630	10	120
	1615	100	0.2	296			
	1625	150	0.3	299			
	1635	200	0.4	289			
	1702	10	0.6	360	1645	10	120
	1706	25	0.4	295	1700	10	120
	1710	50	0.3	291	1715	10	120
	1717	75	0.3	291	1730	10	120
	1723	100	0.2	285			
	1734	150	0.3	286			
	1739	200	0.3	289			
	1802	10	0.6	015	1745	10	120
	1808	25	0.4	301	1800	10	120
	1815	50	0.3	289	1815	10	120
	1821	75	0.2	291	1830	10	120
	1826	100	<0.2				
	1832	150	0.3	288			
	1340	200	0.3	285			
	1900	10	0.6	360	1845	11	110
	1907	25	0.4	297	1900	11	110
	1914	50	0.2	295	1915	11	110
	1924	75	<0.2		1930	11	110
	1930	100	0.2	290	1945	12	140
	1940	150	0.3	287			
	1948	200	0.3	289			
	2015	10	0.4	029	2000	12	140
	2025	25	0.35	010	2015	12	140
	2030	50	0.3	354	2030	12	140
	2042	75	0.3	359	2045	13	140
	2050	100	0.3	360	2100	13	140
	2055	150	<0.2				
	2102	200	<0.2				

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/9/60	2125	10	0.2	026	2115	13	140
	2145	25	0.2	335	2130	13	140
	2155	50	0.2	327	2145	12	120
	2200	75	0.2	319	2200	12	120
	2220	100	0.2	308	2215	12	120
	2237	150	<0.2		2230	12	120
	2255	200	<0.2		2245	10	140
	2310	10	<0.2		2300	10	140
	2345	25	0.3	319	2315	10	140
3/10/60	0005	50	0.2	328	2330	10	140
	0012	75	0.3	308	2345	10	140
	0020	100	<0.2		2400	10	140
	0027	150	<0.2		0015	10	140
	0031	200	<0.2		0030	10	140
	0115	10	0.3	022	0045	10	140
	0120	25	0.4	359	0100	10	140
	0125	50	0.3	360	0115	10	140
	0130	75	0.3	359	0130	10	140
	0136	100	0.3	360	0145	10	140
	0142	150	<0.2				
	0146	200	<0.2				
	0218	10	0.3	022	0200	09	140
	0233	25	0.4	360	0215	09	140
	0236	50	0.3	070	0230	09	140
	0240	75	0.4	068	0245	10	140
	0244	100	0.3	086			
	0249	150	<0.2				
	0253	200	<0.2				
	0320	10	0.5	035	0300	10	140
	0331	25	0.4	036	0315	10	140
	0337	50	0.4	033	0330	10	140
	0342	75	0.5	044	0345	11	140
	0347	100	0.5	067	0400	11	140
	0352	150	<0.2				
	0358	200	<0.2				
	0427	10	0.4	044	0415	11	140
	0434	25	0.4	036	0430	11	140
	0439	50	0.4	034	0445	10	140
	0445	75	0.4	061	0500	10	140
	0449	100	0.5	068			
	0453	150	<0.2				
	0500	200	<0.2				

Date	Current				Wind		
	Time (EST)	Depth (meters)	Speed (knots)	Direction (degrees)	Time (EST)	Speed (knots)	Direction (degrees)
3/10/60	0537	10	0.2	046	0515	10	140
	0548	25	0.25	020	0530	10	140
	0556	50	0.2	351	0545	10	140
	0559	75	0.3	007	0600	10	140
	0612	100	0.4	021	0615	10	140
	0619	150	<0.2		0630	10	140
	0624	200	<0.2				
	0645	10	0.2	055	0645	08	140
	0652	25	0.2	061	0700	08	140
	0701	50	0.3	032	0715	08	140
	0707	75	0.3	029	0730	08	140
	0712	100	0.5	052	0745	08	150
	0730	150	<0.2				
	0735	200	<0.2				
	0800	10	0.2	360	0800	08	150
	0820	25	<0.2	353	0815	08	150
	0830	50	<0.2	360	0830	08	150
	0836	75	<0.2		0845	04	150
	0840	100	0.4	354	0900	04	150
	0845	150	<0.2		0915	04	150
	0850	200	<0.2				
	0930	10	0.4	360	0930	04	150
	0940	25	0.3	360	0945	04	160
	0945	50	<0.2		1000	04	160
	0950	75	<0.2		1015	04	160
	0955	100	<0.2				
	1000	150	<0.2				
	1005	200	0.3	088			
	1030	10	0.3	306	1030	04	160
	1036	25	0.3	328	1045	04	160
	1042	50	<0.2		1100	07	160
	1045	75	<0.2		1115	07	160
	1057	100	<0.2	327	1130	07	160
	1100	150	<0.2	360			
	1110	200	0.3	360			
	1138	10	0.3	313	1145	07	160
	1143	25	0.4	343	1200	03	020
	1150	50	0.2	360	1215	03	020
	1200	75	<0.2	332	1230	03	020
	1215	100	0.2	353	1245	03	020
	1225	150	0.2	049			
	1232	200	0.35	057			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/10/60	1300	10	0.4	025	1300	03	170
	1307	25	0.4	360	1315	03	170
	1310	50	< 0.2	337	1330	03	170
	1328	75	0.25	345	1345	03	170
	1332	100	< 0.2				
	1337	150	0.3	032			
	1345	200	0.35	051			
	1405	10	0.5	022	1400	05	170
	1420	25	0.4	347	1415	06	170
	1425	50	< 0.2		1430	06	170
	1427	75	0.25	346	1445	06	180
	1440	100	0.3	360	1500		180
	1445	150	0.4	041			
	1450	200	0.5	062			
	1515	10	0.5	360	1515	06	180
	1525	25	0.4	353	1530	06	180
	1530	50	0.3	345	1545	06	180
	1535	75	0.2	350	1600	06	180
	1543	100	0.4	044	1615	06	180
	1547	150	0.45	061	1630	06	180
	1558	200	0.5	071			
	1645	10	0.5	020	1645	07	180
	1655	25	0.3	358	1700	07	180
	1705	50	0.2	344	1715	07	180
	1712	75	< 0.2		1730	07	180
	1718	100	0.3	033			
	1724	150	0.3	052			
	1729	200	0.3	069			
	1746	10	0.5	026	1745	04	180
	1750	25	< 0.2		1800	04	180
	1759	50	< 0.2		1815	04	180
	1802	75	< 0.2		1830	04	180
	1805	100	0.3	359			
	1810	150	0.4	050			
	1817	200	0.2	061			
	1840	10	0.5	025	1845	04	050
	1843	25	0.3	357	1900	08	360
	1850	50	0.3	345	1915	08	360
	1856	75	< 0.2				
	1902	100	0.3	045			
	1907	150	0.3	054			
	1914	200	0.3	051			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/10/60	1937	10	0.5	023	1930	08	360
	1940	25	<0.2		1945	08	360
	1944	50	<0.2		2000	09	360
	1950	75	<0.2		2015	09	360
	1955	100	0.3	359	2030	09	360
	2000	150	0.3	044			
	2005	200	<0.2				
	2035	10	0.5	021	2045	09	360
	2039	25	0.3	356	2100	09	360
	2044	50	0.2	319	2115	09	360
	2050	75	0.3	354	2130	09	360
	2055	100	0.3	359			
	2100	150	0.4	049			
	2105	200	0.2	066			
	2140	10	0.5	360	2145	09	360
	2144	25	<0.2		2200	10	360
	2147	50	0.25	316	2215	10	360
	2152	75	0.3	339	2230	10	360
	2158	100	0.25	353			
	2204	150	0.3	036			
	2210	200	<0.2				
	2245	10	0.45	022	2245	10	360
	2249	25	<0.2		2300	10	360
	2251	50	0.2	328	2315	10	360
	2257	75	<0.2		2330	10	360
	2300	100	0.2	349	2345	10	360
	2307	150	0.3	035			
	2312	200	<0.2				
	2350	10	0.5	028	2400	08	360
	2355	25	0.3	352	0015	08	360
3/11/60	0002	50	<0.2		0030	08	360
	0005	75	0.2	340	0045	08	360
	0015	100	0.3	347			
	0025	150	0.4	046			
	0035	200	0.2	027			
	0100	10	0.4	032	0100	08	360
	0105	25	0.3	357	0115	08	360
	0110	50	0.3	360	0130	08	360
	0117	75	0.3	022	0145	08	360
	0125	100	0.3	020			
	0128	150	0.4	047			
	0134	200	0.3	024			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/11/60	0204	10	0.4	338	0200	08	360
	0208	25	0.3	353	0215	08	360
	0215	50	0.35	018	0230	08	360
	0218	75	0.4	026	0245	08	360
	0223	100	0.45	033			
	0228	150	0.5	026			
	0234	200	0.5	027			
	0305	10	0.5	054	0300	06	360
	0308	25	0.6	031	0315	06	360
	0314	50	0.6	046	0330	06	360
	0318	75	0.5	052	0345	06	360
	0323	100	0.5	041			
	0328	150	0.5	051			
	0345	200	0.5	033			
	0410	10	0.6	027	0400	07	020
	0417	25	0.5	023	0415	07	020
	0423	50	0.5	019	0430	07	020
	0428	75	0.6	046	0445	07	020
	0432	100	0.5	039			
	0435	150	0.5	051			
	0442	200	0.5	036			
	0512	10	0.4	040	0500	06	020
	0515	25	0.4	360	0515	06	020
	0520	50	0.6	019	0530	06	020
	0530	75	0.4	033	0545	06	020
	0535	100	0.5	038			
	0540	150	0.5	046			
	0550	200	0.5	031			
	0620	10	0.5	035	0600	07	090
	0623	25	0.5	023	0615	07	090
	0630	50	0.3	020	0630	07	090
	0638	75	0.3	011	0645	07	120
	0650	100	0.3	020	0700	07	120
	0655	150	0.4	042			
	0700	200	0.5	025			
	0745	10	0.6	047	0715	07	120
	0749	25	0.5	031	0730	07	120
	0752	50	0.4	022	0745	07	130
	0756	75	0.4	039	0800	07	130
	0802	100	0.4	036	0815	07	130
	0805	150	0.4	036	0830	07	130
	0811	200	0.5	041			

Date	Current				Wind		
	Time (EST)	Depth (meters)	Speed (knots)	Direction (degrees)	Time (EST)	Speed (knots)	Direction (degrees)
3/11/60	0839	10	0.6	051	0845	08	140
	0843	25	0.5	045	0900	08	140
	0846	50	0.4	051	0930	08	140
	0851	75	0.5	042			
	0901	100	0.5	039			
	0906	150	0.4	034			
	0910	200	0.5	060			
	0940	10	0.5	035	0945	10	160
	0943	25	0.5	027	1000	10	160
	0945	50	0.3	048	1015	10	160
	0952	75	0.4	043	1030	10	160
	0958	100	0.3	028			
	1004	150	0.4	026			
	1010	200	0.6	050			
	1040	10	0.5	035	1045	10	160
	1046	25	0.4	360	1100	10	160
	1050	50	0.3	360	1115	10	160
	1055	75	0.3	360			
	1100	100	0.3	357			
	1106	150	0.4	019			
	1112	200	0.5	044			
	1133	10	0.5	038	1130	10	160
	1137	25	0.4	355	1145	10	180
	1142	50	0.4	360	1200	10	180
	1146	75	0.3	354			
	1152	100	0.3	335			
	1158	150	0.4	021			
	1204	200	0.5	053			
	1224	10	0.5	045	1215	10	180
	1228	25	0.4	360	1230	10	180
	1233	50	0.4	042	1245	10	180
	1237	75	0.3	360			
	1242	100	0.3	360			
	1251	150	0.5	028			
	1256	200	0.5	054			
	1317	10	0.5	079	1300	11	180
	1321	25	0.5	038	1315	11	180
	1325	50	0.5	038	1330	11	180
	1330	75	0.4	040	1345	11	140
	1335	100	0.3	359			
	1339	150	0.5	026			
	1344	200	0.45	056			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/11/60	1404	10	0.6	065	1400	11	140
	1408	25	0.5	030	1415	11	140
	1412	50	0.5	035	1430	11	140
	1416	75	0.5	051			
	1420	100	0.5	035			
	1424	150	0.6	036			
	1428	200	0.3	064			
	1448	10	0.6	048	1500	12	140
	1454	25	0.5	022	1515	12	140
	1459	50	0.5	028	1530	12	140
	1502	75	0.4	028			
	1506	100	0.5	036			
	1510	150	0.6	060			
	1514	200	0.4	084			
	1536	10	0.8	061	1545	13	140
	1539	25	0.5	029	1600	13	140
	1542	50	0.3	064	1615	13	140
	1550	75	0.6	054	1630	13	140
	1553	100	0.6	059			
	1557	150	0.6	068			
	1600	200	0.6	087			
	1708	10	0.8	062	1700	11	140
	1720	25	0.5	057	1715	11	140
	1722	50	0.4	052	1730	11	140
	1727	75	0.6	038	1745	11	140
	1734	100	0.6	043			
	1737	150	0.7	048			
	1740	200	0.6	058			
	1802	10	0.8	070	1800	11	150
	1815	25	0.5	032	1815	11	150
	1819	50	0.6	028	1830	11	150
	1823	75	0.6	047	1845	09	160
	1826	100	0.6	049			
	1830	150	0.6	067			
	1835	200	0.6	079			
	1900	10	0.3	040	1900	09	160
	1909	25	< 0.2		1915	09	160
	1912	50	0.5	042	1930	09	160
	1915	75	0.6	045			
	1918	100	0.5	053			
	1923	150	0.5	057			
	1927	200	0.5	075			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/11/60	1950	10	<0.2		1945	09	160
	1955	25	<0.2		2000	08	160
	2000	50	0.4	360	2015	08	160
	2003	75	0.5	360	2030	08	160
	2008	100	0.5	360			
	2020	150	0.5	017			
	2023	200	<0.2				
	2049	10	0.4	015	2045	08	160
	2058	25	<0.2		2100	10	180
	2100	50	0.5	045	2115	10	180
	2105	75	0.6	059	2130	10	180
	2110	100	0.6	063			
	2115	150	0.5	063			
	2120	200	<0.2				
	2145	10	0.2	340	2145	05	180
	2200	25	<0.2		2200	05	180
	2205	50	0.4	035	2215	05	180
	2212	75	0.5	360	2230	05	180
	2218	100	0.5	030	2245	07	180
	2223	150	0.5	063			
	2232	200	0.3	059			
	2300	10	0.3	250	2300	07	180
	2313	25	<0.2		2315	07	180
	2315	50	0.3	097	2330	07	180
	2322	75	0.4	086	2345	07	180
	2328	100	0.4	090			
	2333	150	0.4	078			
	2345	200	<0.2				
3/12/60	0014	10	0.4	170	0030	07	180
	0020	25	<0.2		0045	09	250
	0023	50	0.4	101	0100	09	250
	0030	75	0.5	081			
	0036	100	0.5	077			
	0040	150	0.5	072			
	0045	200	0.2	126			
	0110	10	0.4	158	0115	09	250
	0115	25	<0.2		0130	09	250
	0119	50	0.4	102	0145	09	250
	0124	75	0.5	078			
	0127	100	0.5	075			
	0130	150	0.5	068			
	0138	200	<0.2				

Date	Current				Wind		
	Time (EST)	Depth (meters)	Speed (knots)	Direction (degrees)	Time (EST)	Speed (knots)	Direction (degrees)
3/12/60	0210	10	0.3	132	0200	12	250
	0216	25	<0.2		0215	12	250
	0220	50	0.3	081	0230	12	250
	0227	75	0.6	074	0245	12	250
	0234	100	0.6	078			
	0240	150	0.6	071			
	0245	200	<0.2				
	0314	10	0.35	118	0300	13	220
	0321	25	<0.2		0315	13	220
	0323	50	<0.2		0330	13	220
	0330	75	0.6	057	0345	13	220
	0334	100	0.65	060			
	0340	150	0.6	061			
	0355	200	0.3	031			
	0424	10	0.3	094	0400	13	230
	0428	25	0.3	106	0415	13	230
	0434	50	0.4	086	0430	12	230
	0439	75	0.6	064	0445	13	230
	0442	100	0.8	067			
	0449	150	0.6	082			
	0456	200	0.3	090			
	0520	10	0.3	083	0500	14	260
	0524	25	0.3	086	0515	14	260
	0530	50	0.4	106	0530	14	260
	0535	75	0.6	055	0545	14	260
	0538	100	0.7	060			
	0544	150	0.7	062			
	0552	200	0.4	054			
	0618	10	0.3	086	0600	12	270
	0624	25	0.35	105	0615	12	270
	0628	50	0.4	110	0630	12	270
	0632	75	0.4	068	0645	12	270
	0637	100	0.7	056			
	0642	150	0.7	060			
	0646	200	0.3	043			
	0705	10	0.6	115	0700	11	240
	0710	25	0.5	147	0715	11	240
	0716	50	0.4	118	0730	11	240
	0730	75	0.5	097	0745	10	260
	0733	100	0.7	080			
	0750	150	0.7	090			
	0755	200	0.4	064			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/12/60	0810	10	0.6	113	0800	10	260
	0815	25	0.4	136	0815	10	260
	0818	50	0.5	116	0830	10	260
	0823	75	0.4	114			
	0828	100	0.6	089			
	0833	150	0.7	090			
	0841	200	0.4	060			
	0903	10	0.6	127	0915	11	260
	0907	25	0.4	128	0930	11	260
	0911	50	0.4	112	0945	11	260
	0918	75	0.4	112			
	0924	100	0.6	071			
	0930	150	0.7	064			
	0935	200	0.5	042			
	0957	10	0.7	129	1000	11	250
	1000	25	0.5	151	1015	11	250
	1005	50	0.2	120	1030	11	250
	1013	75	0.4	106			
	1020	100	0.5	073			
	1025	150	0.7	073			
	1028	200	0.5	043			
	1050	10	0.8	123	1045	10	240
	1055	25	0.4	145	1100	10	240
	1100	50	0.2	109	1115	10	240
	1113	75	0.3	107	1130	10	240
	1117	100	0.5	075			
	1122	150	0.7	061			
	1125	200	0.6	035			
	1155	10	0.7	143	1145	16	340
	1203	25	0.4	125	1200	16	340
	1205	50	0.2	100	1215	16	340
	1213	75	0.3	106	1230	16	340
	1223	100	0.5	084	1245	16	340
	1228	150	0.6	070			
	1235	200	0.5	065			
	1320	10	1.0	126	1300	19	330
	1325	25	0.5	122	1315	19	330
	1330	50	0.2	119	1330	19	330
	1337	75	0.35	113	1345	22	340
	1345	100	0.35	095			
	1353	150	0.6	093			
	1355	200	0.4	100			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/12/60	1410	10	1.0	122	1400	22	340
	1425	25	0.5	132	1415	22	340
	1430	50	0.3	096	1430	22	340
	1445	75	0.4	108	1445	23	020
	1452	100	0.5	100	1500	23	020
	1457	150	0.7	097	1515	23	020
	1500	200	0.35	080	1530	23	020
3/13/60	1530	10	0.5	192	1530	08	070
	1533	25	0.6	145	1545	08	070
	1537	50	0.5	153	1600	10	070
	1542	75	0.3	141	1616	10	070
	1547	100	0.5	126			
	1551	150	0.4	159			
	1555	200	< 0.2				
	1620	10	0.4	125	1630	10	070
	1622	25	0.6	158	1645	10	070
	1628	50	0.5	143	1700	14	100
	1630	75	0.5	136			
	1638	100	0.6	127			
	1643	150	0.6	155			
	1647	200	0.3	132			
	1710	10	0.5	137	1715	14	100
	1715	25	0.6	153	1730	14	100
	1725	50	0.6	140	1745	14	100
	1730	75	0.5	135			
	1734	100	0.6	125			
	1737	150	0.6	143			
	1743	200	0.4	140			
	1809	10	0.4	130	1800	14	080
	1814	25	0.6	129	1830	14	080
	1817	50	0.6	127	1845	11	080
	1822	75	0.4	135			
	1830	100	0.7	122			
	1835	150	0.5	126			
	1845	200	0.5	124			
	1903	10	0.6	120	1915	11	080
	1906	25	0.6	129	1930	11	080
	1910	50	0.6	126	1945	12	080
	1915	75	0.6	126			
	1916	100	0.65	126			
	1928	150	0.6	124			
	1930	200	0.4	126			

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Wind Speed (knots)	Wind Direction (degrees)
3/13/60	1955	10	0.5	155	2000	12	080
	2004	25	0.4	150	2015	12	080
	2008	50	0.5	146	2030	12	080
	2014	75	0.5	145			
	2018	100	0.6	132			
	2022	150	0.5	156			
	2026	200	0.3	145			
	2045	10	0.5	133	2045	10	080
	2050	25	0.6	186	2100	10	080
	2055	50	0.5	147	2115	10	080
	2100	75	0.5	145	2130	10	080
	2104	100	0.5	136			
	2108	150	0.5	126			
	2115	200	0.3	128			
	2135	10	0.6	129	2145	10	080
	2145	25	0.6	153	2200	12	080
	2150	50	0.6	147	2215	12	080
	2154	75	0.6	135			
	2158	100	0.6	135			
	2200	150	0.5	125			
	2205	200	0.4	117			
	2223	10	0.6	129	2230	12	080
	2228	25	0.6	150	2245	12	080
	2230	50	0.5	128	2300	10	070
	2238	75	0.6	145	2315	10	070
	2248	100	0.6	128	2330	10	070
	2253	150	0.4	130	2345	10	070
	2255	200	0.3	135	2400	11	070
3/14/60	0010	10	0.5	128	0015	11	070
	0020	25	0.6	168	0030	11	070
	0024	50	0.5	136	0045	11	070
	0027	75	0.5	127			
	0030	100	0.5	120			
	0034	150	0.5	135			
	0040	200	0.2	132			
	0103	10	0.5	133	0100	11	090
	0106	25	0.5	168	0115	11	090
	0112	50	0.4	162	0130	11	090
	0116	75	0.5	129			
	0120	100	0.4	138			
	0125	150	0.5	135			
	0129	200	<0.2				

Date	Current				Wind		
	Time (EST)	Depth (meters)	Speed (knots)	Direction (degrees)	Time (EST)	Speed (knots)	Direction (degrees)
3/14/60	0148	10	0.5	124	0145	11	090
	0153	25	0.4	169	0200	12	090
	0156	50	0.5	145	0215	12	090
	0200	75	0.5	140	0230	12	090
	0204	100	0.5	135			
	0207	150	0.4	171			
	0215	200	0.2	128			
	0235	10	0.6	120	0245	12	090
	0255	25	0.5	164	0300	11	070
	0300	50	0.4	126	0315	11	070
	0305	75	0.5	145	0330	11	070
	0310	100	0.4	146	0345	11	070
	0320	150	0.4	155			
	0324	200	0.2	120			
	0400	10	0.6	133	0400	12	070
	0405	25	0.6	146	0415	12	070
	0408	50	0.4	155	0430	12	070
	0414	75	0.6	128			
	0418	100	0.5	124			
	0422	150	0.5	146			
	0429	200	0.3	121			
	0458	10	0.6	145	0445	12	070
	0502	25	0.6	146	0500	13	070
	0505	50	0.5	136	0515	13	070
	0510	75	0.4	138	0530	13	070
	0515	100	0.4	130			
	0520	150	0.3	131			
	0527	200	0.2	128			
	0553	10	0.6	115	0545	13	070
	0558	25	0.5	149	0600	12	070

Table C-2. Summary of Water Current Data - Area R2 TOTO February 1962

Ship moor - three point
Date - 1-9 February 1962

Location - 24°24.7'N 77°32.3'W
Current meter - Roberts No. W14 LVC and 130 LVC

Date	Time (EST)	Current		
		Depth (meters)	Speed (knots)	Direction (degrees)
2/1/62	2300	50	< 0.1	-
	2310	100	< 0.1	-
	2320	150	< 0.1	-
	2330	200	< 0.1	-
	2348	400	0.21	015
	2400	600	-	
2/2/62	0010	800	-	-
	0030	1000	< 0.1	-
	0048	1200	< 0.1	185
	0117	1500	< 0.1	-
	0230	1500	< 0.1	210
2/4/62	1124	50	-	-
	1132	100	-	-
	1155	150	-	-
	1243	200	-	-
	1[illegible]10	600	0.12	-
2/5/62	1548	10	0.16	210
	1618		0.18	215
	1700		0.26	215
	1735		0.32	215
	1800		0.30	225
	1835		0.35	220
	1900		0.35	220
	1930		0.30	220
	2000		0.30	215
	2030		0.32	215
	2100		0.24	210
	2130		0.22	210
	2200		0.22	215
	2231		0.20	215
	2236		0.20	215
	2300		0.14	215

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)
2/6/62	0005	10	0.12	210
	0030		<0.10	240
	0150		0.10	210
	0230		0.16	215
	0330		0.16	195
	0400		0.16	225
	0430		0.25	215
	0500		0.25	220
	0530		0.30	215
	0600		0.30	200
	0630		0.34	200
	0700		0.34	205
	0730		0.32	210
	0800		0.32	200
	0830		0.28	200
	0900		0.24	195
	0928	50	0.24	145
	1003		0.25	170
	1030		0.28	125
	1100		0.22	085
	1130		0.26	045
	1200		0.30	060
	1230		0.32	055
	1300		0.34	050
	1330		0.34	045
	1400		0.30	045
	1430		0.26	055
	1500		0.24	050
	1530		0.20	70-150 ?
	1603		0.18	80-150 ?
	1628		0.14	085
	1657		-	-
	1730		0.12	060 ?
	1800		-	-
	1900		-	-
	1930		0.10	160
	2000		0.10	130
	2030		0.10	110
	2100		0.10	-
	2135		0.14	090
	2204		0.12	090
	2207		0.14	085
	2242		0.14	060
	2304		0.20	055
	2330		0.22	050
	2400		0.25	055

Date	Time (EST)	Current: Depth (meters)	Current: Speed (knots)	Current: Direction (degrees)
2/7/62	0030	50	0.28	055
	0100		0.32	360
	0125	↓	0.32	030
	0140	10	0.28	030
	0145	3	0.26	020
	0200	50	0.34	030
	0230		0.32	030
	0300		0.32	030
	0330		0.26	030
	0400		0.26	030
	0430		0.18	025
	0500		0.14	025
	0530		-	-
	1050		0.20	015
	1130	↓	0.20	0[illegible]50
	1153	100	0.20	360-010
	1230		0.25	360-010
	1257		0.30	360
	1330		0.30	010
	1410		0.32	360-010
	1435		0.32	360-020
	1500		0.32	360
	1530		0.30	360-010
	1600		0.22	360
	1630		-	-
	1700		-	-
	1730		0.12	010
	1805		0.10	360
	1837		0.10	220
	1900		0.10	-
	1940		0.16	190
	2000		0.14	180
	2048		0.14	135
	2105		0.14	155
	2130		0.10	270
	2200		0.12	090
	2226		< 0.10	090
	2300	↓	< 0.10	150

Date	Time (EST)	Current		
		Depth (meters)	Speed (knots)	Direction (degrees)
2/[illegible]	0408	100	0.32	010
	0430		0.24	045
	0500		0.20	025
	0530		0.24	035
	0600		0.18	165
	0630		<0.10	-
	0700		0.22	1[illegible]0
	0730		0.22	160
	0800		0.14	180
	0830		0.15	160
	[illegible]		<0.10	-
	[illegible]		0.14	180
	[illegible]		-	-
	[illegible]		<0.10	-
	[illegible]	3	0.34	360-010
	[illegible]	3	0.30	360
	1355	50	0.28	350
	1402	100	0.26	020
	14[illegible]	150	0.26	360
	14[illegible]0		0.28	030
	[illegible]		0.30	010
	[illegible]30		0.30	360
	[illegible]		0.32	035
	[illegible]		0.24	020
	1700		0.20	300
	1730		0.14	360
	1805		-	-
	[illegible]		-	-
	[illegible]		0.10	-
	[illegible]30		0.10	215
	2000		<0.10	110-200

Date	Time (EST)	Depth (meters)	Current Speed (knots)	Current Direction (degrees)	Time (EST)	Depth (meters)	Current Speed (knots)	Current Direction (degrees)
2/8/62	2030	150	0.18	185	2020	15	0.16	-
					2030	↓	0.20	-
	2100	↓	0.26	175	2100		0.22	-
	2130		0.30	175	2130		0.20	-
	2200		0.26	170				
	2230		0.22	180	2230		0.22	-
	2300		0.18	190	2300		0.22	-
	2330		0.18	140	2330		0.14	-
	2400		0.18	135	2400		0.16	140
2/9/62	0035	150	0.16	140	0035	15	0.18	-
	0100	↓	0.18	170	0100	↓	0.22	-
	0135		0.14	035	0130		0.18	-
	0145		0.16	020	0138		0.14	-
	0155		0.14	180				
	0200		0.16	060				
	0230		0.18	030				
	0300		0.18	025	0300		0.18	-
	0330		0.14	025	0330		0.18	-
	0400		0.18	015	0400		0.16	-
	0500		0.16	100	0500		< 0.10	-
	0530		0.18	160				
	0630		-	-				
	0700		-	-	0700		0.14	-
	0800		0.22	170	0800		0.10	-
	0830		0.28	180	0830		0.30	-
	0900		0.28	185				
	0930		0.32	170	1000	3	0.34	180
	1000		0.34	160	1010	15	0.46	180
	1030		0.20	165	1021	↓	0.30	190
	1100		0.14	210	1030		0.32	195
	1130		0.20	190	1100		0.28	190
	1230		0.18	175	1120		0.26	165
	1300		< 0.10	090	1125		0.28	180
	1330		-	-	1132		0.28	180
	1400		-	-	1230		0.20	120-200
	1430		-	-	1300		0.22	200
	1500		-	-	1640		0.18	320
					1710		0.18	280

APPENDIX D

Summary of water current data taken in the Tilt Area in TOTO. A tilt device was used on an experimental array and the data taken were processed and computed to provide information on the bottom water currents.

Table D-1. Summary of Bottom Water Current Data - Tilt Area TOTO February 1962

Ship moor - four point
Date - 1-8 February 1962
Location - 24°25.0'N 77°30.0'W
Measurements made with tilt device
Water depth - ≈1500 meters

Date	Time (EST)	Current Depth (meters)	Current Speed (knots)	Current Direction (degrees)
2/1/62	2200	~ 1500	0.160	208
	2315		0.134	207
	2345		0.137	207
2/2/62	0145		0.152	207
	0215		0.154	210
	0245		0.157	211
	0315		0.157	211
	0330		0.154	211
	0345		0.157	212
	0400		0.157	215
	0500		0.152	210
	0530		0.160	210
	0615		0.145	221
	0700		0.160	027
	0715		0.145	040
	0745		0.156	025
	1530		0.125	022
	1900		0.126	290
	2000		0.125	292
	2100		0.117	300
	2200		0.117	296
	2230		0.108	295
	2400		0.115	297
2/3/62	0200		0.115	268
	0230		0.117	266
	0315		0.116	270
	0430		0.134	280
	0445		0.138	288
	0515		0.144	292
	0615		0.152	296
	0630		0.155	297
	0645		0.151	300
	0915		0.152	312
	0930		0.125	317
	0945		0.151	307
	1045		0.134	305

Date	Time (EST)	Current Depth (meters)	Speed (knots)	Direction (degrees)
2/3/62	1100	~1500	0.125	305
	1130		0.153	305
	1145		0.149	283
	1200		0.149	283
	1215		0.144	283
	2000		0.167	305
	2030		0.144	306
	2100		0.167	306
	2145		0.160	307
	2215		0.146	305
	2230		0.160	312
	2300		0.153	300
	2315		0.140	310
	2330		0.129	306
	2400		0.126	304
2/4/62	0100		0.122	294
	0145		0.122	292
	0200		0.124	292
	0230		0.127	285
	0300		0.130	275
	0315		0.137	278
	0330		0.141	285
	0345		0.148	292
	0400		0.159	293
	0415		0.158	295
	0445		0.157	300
	0500		0.164	302
	0515		0.160	304
	0530		0.163	306
	0545		0.160	297
	0600		0.169	311
	0630		0.159	310
	0700		0.162	312
	1000		0.073	341
	1015		0.145	314
	1030		0.072	331
	1045		0.137	312
	1100		0.102	310
	1530		0.117	281
	2015		0.124	274
	2030		0.125	280
	2100		0.125	280
	2115		0.128	284
	2130		0.124	284
	2145		0.128	284
	2300		0.124	277
	2345		0.118	265

Date	Time (EST)	Current		
		Depth (meters)	Speed (knots)	Direction (degrees)
2/5/62	0015	~1500	0.114	260
	0115		0.121	220
	0145		0.134	215
	0400		0.161	222
	0600		0.164	232
	0645		0.155	235
	0700		0.145	220
	0800		0.135	240
	1800		0.158	215
	1900		0.144	215
	1930		0.127	226
	2000		0.129	225
	2130		0.122	230
2/6/62	0015		0.114	260
	0100		0.108	240
	0115		0.114	235
	0400		0.104	230
	0700		0.104	232
2/7/62	0530		0.112	229
	0900		0.123	290
	1000		0.152	295
	2100		0.159	320
	2315		0.124	308
2/8/62	0015		0.164	314
	0115		0.124	306

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